Appendix B: Joint Claim Construction Chart

Alleged Indefinite Means-Plus-Function Terms				
No.	**’156 Patent Terms**	**Plaintiff’s Proposed Construction**	**Kyocera & ZTE’s Proposed Construction**	**Huawei & Coolpad’s Proposed Construction**
	a cell phone functionality; and an RF communication functionality separate from said cell phone functionality; **a module to establish simultaneous communication paths from said multimode cell phone using both said cell phone functionality and said RF communication functionality**; and an automatic switch over module, in communication with both said cell phone functionality and said RF communication functionality, operable to switch a communication path established on one of said cell phone	not a nonce word here. Instead, the “module to establish simultaneous communication paths from said multimode cell phone using both said cell phone functionality and said RF communication functionality” is itself sufficient structure. A POSA would know this is a structure for RF communications through a genus of RF communication types well known in the art. In the alternative, to the extent the Court determines that this claim is governed by 112 ¶ 6, BNR proposes the following Function and Structure, and disagrees	Function: “establish simultaneous communication paths from said multimode cell phone using both said cell phone functionality and said RF communication functionality” Structure: Indefinite for lack of corresponding structure in the patent specification. **Intrinsic Support:** Claims: ’156 Patent: Claim 1.	Function: “establish simultaneous communication paths from said multimode cell phone using both said cell phone functionality and said RF communication functionality” Structure: Fig. 1 (element 101); Fig. 2 steps 202-208; Fig. 4 steps 402-408; 4:50-67; 7:1-16. **Intrinsic Support:** Claims: ’156 Patent: Claims 1, 2, 3.

Appendix B: Joint Claim Construction Chart

Alleged Indefinite Means-Plus-Function Terms				
No.	**’156 Patent Terms**	**Plaintiff’s Proposed Construction**	**Kyocera & ZTE’s Proposed Construction**	**Huawei & Coolpad’s Proposed Construction**
	functionality and said RF communication functionality, with another communication path later established on the other of said cell phone functionality and said RF communication functionality.	that the term is indefinite for lack of corresponding structure: Function: establish simultaneous communication paths from said multimode cell phone using both said cell phone functionality and said RF communication functionality Structure: Corresponding structure for the alleged function exists in at least the following portions of the patent specification, or their equivalents: Figs. 1, 3, Col. 3:48–4:49; 4:54–5:62; 6:3–55; 6:60–8:5	Figures: ’156 Patent: Figs. 1–6. Specification: ’156 Patent: 4:1–6, 7:9–12, 7:51–55; *see also* Abstract, 1:51–2:4, 2:11–32, 3:48–4:49, 4:50–5:6, 5:21–6:55, 7:1–26, 7:45–8:5. Prosecution History: U.S. Patent Appl. No. 09/888,493, Dec. 8, 2004 Office Action; Jan. 6, 2005 Response to Office Action; Apr. 26, 2005 Notice of Allowance. U.S. Pat. No. 5,842,122 (“Schellinger”).	Figures: ’156 Patent: Figs. 1–6. Specification: ’156 Patent: Abstract; 1:51–2:4; 2:10–33, 3:26–34, 3:48–5:32; 5:37–8:5. Prosecution History: U.S. Patent Appl. No. 09/888,493, Dec. 8, 2004 Office Action; Jan. 6, 2005 Response to Office Action; Apr. 26, 2005 Notice of Allowance. U.S. Pat. No. 5,842,122 (“Schellinger”). **Extrinsic Support:** Defendants may rely on expert opinion from Dr.

Appendix B: Joint Claim Construction Chart

Alleged Indefinite Means-Plus-Function Terms				
No.	**'156 Patent Terms**	**Plaintiff's Proposed Construction**	**Kyocera & ZTE's Proposed Construction**	**Huawei & Coolpad's Proposed Construction**
		Intrinsic Evidence: Figs. 1, 3, Col. 3:48–4:49; 4:54–5:62; 6:3–55; 6:60–8:5. **Extrinsic Evidence:** BNR may rely on the testimony of Dr. Vijay Madisetti that this claim term should be understood in accordance with its plain and ordinary meaning, what the plain and ordinary meaning of these terms is, that this term is not subject to 112 ¶ 6, why Defendants' proposed construction is unsupported by any intrinsic or extrinsic evidence, and, in the alternative, where and how the specification	**Extrinsic Support:** Defendants may rely on expert opinion from Dr. Jonathan Wells and/or Dr. Paul Min regarding the technology background and the state of the art relating to this patent, and/or to establish the understanding of the term by a person of ordinary skill in the art at the time of the alleged inventions, *e.g.*, how the patent's claims, viewed in light of the specification and prosecution inform those skilled in the art about the scope of the term. Dr. Wells and/or Dr. Min may also provide expert	Jonathan Wells and/or Dr. Paul Min regarding the technology background and the state of the art relating to this patent, and/or to establish the understanding of the term by a person of ordinary skill in the art at the time of the alleged inventions, *e.g.*, how the patent's claims, viewed in light of the specification and prosecution inform those skilled in the art about the scope of the term. Dr. Wells and/or Dr. Min may also provide expert opinion rebutting BNR's or its expert's

Appendix B: Joint Claim Construction Chart

Alleged Indefinite Means-Plus-Function Terms				
No.	**'156 Patent Terms**	**Plaintiff's Proposed Construction**	**Kyocera & ZTE's Proposed Construction**	**Huawei & Coolpad's Proposed Construction**
		discloses the claimed function. Further, Dr. Madisetti may also provide opinions rebutting any opinions submitted by Defendants' expert(s). BNR also reserves the right to rely on any Intrinsic or Extrinsic Evidence that Defendants identify for this term. **Statement of Impact:** Defendants' proposed means plus function construction and indefinite arguments predicated on means plus function argument are incorrect and improper. To the extent the Court	opinion rebutting BNR's or its expert's constructions or opinions. **<u>Impact of Proposed Construction:</u>** Finding this term indefinite would render all asserted claims (claim 1) of the '156 Patent invalid.	constructions or opinions. **<u>Impact of Proposed Construction:</u>** The proposed construction may have a claim dispositive impact on the alleged infringement of all asserted claims (claim 1) of the '156 Patent.

Appendix B: Joint Claim Construction Chart

Alleged Indefinite Means-Plus-Function Terms				
No.	**'156 Patent Terms**	**Plaintiff's Proposed Construction**	**Kyocera & ZTE's Proposed Construction**	**Huawei & Coolpad's Proposed Construction**
		believes the claim is governed by 112 ¶ 6, sufficient structure exists in the specification.		
15.	1. A multimode cell phone, comprising: a cell phone functionality; and an RF communication functionality separate from said cell phone functionality; a module to establish simultaneous communication paths from said multimode cell phone using both said cell phone functionality and said RF communication functionality; and **an automatic switch over module, in communication with**	**Construction:** Not a 112 ¶ 6 claim element – "module" is not a nonce word here. Instead, the "an automatic switch over module, in communication with both said cell phone functionality and said RF communication functionality, operable to switch a communication path established on one of said cell phone functionality and said RF communication functionality, with another communication path later established on	**Construction:** This is a 112 ¶ 6 claim element. Function: "in communication with both said cell phone functionality and said RF communication functionality, operable to switch a communication path established on one of said cell phone functionality and said RF communication functionality, with another communication path later established on the other of said cell phone functionality and	**Construction:** This is a 112 ¶ 6 claim element. Function: "automatic switch over of a communication path established on one of said cell phone functionality and said RF communication functionality, with another communication path later established on the other of said cell phone functionality and said RF communication functionality"

Appendix B: Joint Claim Construction Chart

Alleged Indefinite Means-Plus-Function Terms				
No.	**'156 Patent Terms**	**Plaintiff's Proposed Construction**	**Kyocera & ZTE's Proposed Construction**	**Huawei & Coolpad's Proposed Construction**
	both said cell phone functionality and said RF communication functionality, operable to switch a communication path established on one of said cell phone functionality and said RF communication functionality, with another communication path later established on the other of said cell phone functionality and said RF communication functionality.	the other of said cell phone functionality and said RF communication functionality" is itself sufficient structure. A POSA would know this is a structure for RF communications through a genus of RF communication types well known in the art. In the alternative, to the extent the Court determines that this claim is governed by 112 ¶ 6, BNR proposes the following Function and Structure, and disagrees that the term is indefinite for lack of corresponding structure: <u>Function:</u>	said RF communication functionality" <u>Structure</u>: Indefinite for lack of corresponding structure in the patent specification. **<u>Intrinsic Support:</u>** <u>Claims:</u> '156 Patent: Claim 1. <u>Figures:</u> '156 Patent: Fig. 1; *see also* Figs. 2–6. <u>Specification:</u> '156 Patent: 1:53–60, 3:55–59, 4:1–6; *see also* 1:51–2:4, 2:11–32, 3:48–4:49, 4:50–5:6; 5:21–	<u>Structure:</u> Fig. 1 (element 101); Fig. 2 steps 210-212; Fig. 4 steps 410-412; 5:1-7; 7:17-26, claim 1 ("an automatic switch over module, in communication with both said cell phone functionality and said RF communication functionality"). **<u>Intrinsic Support:</u>** <u>Claims:</u> '156 Patent: Claims 1, 2, 3. <u>Figures:</u> '156 Patent: Figs. 1–6.

Appendix B: Joint Claim Construction Chart

Alleged Indefinite Means-Plus-Function Terms				
No.	**'156 Patent Terms**	**Plaintiff's Proposed Construction**	**Kyocera & ZTE's Proposed Construction**	**Huawei & Coolpad's Proposed Construction**
		in communication with both said cell phone functionality and said RF communication functionality, operable to switch a communication path established on one of said cell phone functionality and said RF communication functionality, with another communication path later established on the other of said cell phone functionality and said RF communication functionality <u>Structure</u>: Corresponding structure for the alleged function exists in at least the following portions of the patent specification, or their equivalents:	6:55, 7:1–26, 7:45–8:5, Abstract. <u>Prosecution History:</u> U.S. Patent Appl. No. 09/888,493, Dec. 8, 2004 Office Action; Jan. 6, 2005 Response to Office Action; Apr. 26, 2005 Notice of Allowance. U.S. Pat. No. 5,842,122 ("Schellinger"). **<u>Extrinsic Support:</u>** Defendants may rely on expert opinion from Dr. Jonathan Wells and/or Dr. Paul Min regarding the technology background and the state of the art relating to this patent, and/or to	<u>Specification:</u> '156 Patent: Abstract; 1:51–2:4; 2:10–33, 3:26–34, 3:48–5:32; 5:37–8:5. <u>Prosecution History:</u> U.S. Patent Appl. No. 09/888,493, Dec. 8, 2004 Office Action; Jan. 6, 2005 Response to Office Action; Apr. 26, 2005 Notice of Allowance. U.S. Pat. No. 5,842,122 ("Schellinger"). **<u>Extrinsic Support:</u>** Defendants may rely on expert opinion from Dr. Jonathan Wells and/or Dr. Paul Min regarding the technology

Appendix B: Joint Claim Construction Chart

Alleged Indefinite Means-Plus-Function Terms				
No.	**'156 Patent Terms**	**Plaintiff's Proposed Construction**	**Kyocera & ZTE's Proposed Construction**	**Huawei & Coolpad's Proposed Construction**
		Figs. 1, 3, Col. 3:48–4:49; 4:54–5:62; 6:3–55; 6:60–8:5 **Intrinsic Evidence:** Figs. 1, 3, Col. 3:48–4:49; 4:54–5:62; 6:3–55; 6:60–8:5 **Extrinsic Evidence:** BNR may rely on the testimony of Dr. Vijay Madisetti that this claim term should be understood in accordance with its plain and ordinary meaning, what the plain and ordinary meaning of these terms is, that this term is not subject to 112 ¶ 6, why Defendants' proposed construction is	establish the understanding of the term by a person of ordinary skill in the art at the time of the alleged inventions, *e.g.*, how the patent's claims, viewed in light of the specification and prosecution inform those skilled in the art about the scope of the term. Dr. Wells and/or Dr. Min may also provide expert opinion rebutting BNR's or its expert's constructions or opinions. **<u>Impact of Proposed Construction:</u>** Finding this term indefinite would render	background and the state of the art relating to this patent, and/or to establish the understanding of the term by a person of ordinary skill in the art at the time of the alleged inventions, *e.g.*, how the patent's claims, viewed in light of the specification and prosecution inform those skilled in the art about the scope of the term. Dr. Wells and/or Dr. Min may also provide expert opinion rebutting BNR's or its expert's constructions or opinions.

Appendix B: Joint Claim Construction Chart

Alleged Indefinite Means-Plus-Function Terms				
No.	**'156 Patent Terms**	**Plaintiff's Proposed Construction**	**Kyocera & ZTE's Proposed Construction**	**Huawei & Coolpad's Proposed Construction**
		unsupported by any intrinsic or extrinsic evidence, and, in the alternative, where and how the specification discloses the claimed function. Further, Dr. Madisetti may also provide opinions rebutting any opinions submitted by Defendants' expert(s). BNR also reserves the right to rely on any Intrinsic or Extrinsic Evidence that Defendants identify for this term. **Statement of Impact:** Defendants' proposed means plus function construction and	all asserted claims (claim 1) of the '156 Patent invalid.	**Impact of Proposed Construction:** The proposed construction may have a claim dispositive impact on the alleged infringement of all asserted claims (claim 1) of the '156 Patent.

Appendix B: Joint Claim Construction Chart

Alleged Indefinite Means-Plus-Function Terms				
No.	**'156 Patent Terms**	**Plaintiff's Proposed Construction**	**Kyocera & ZTE's Proposed Construction**	**Huawei & Coolpad's Proposed Construction**
		indefinite arguments predicated on means plus function argument are incorrect and improper. To the extent the Court believes the claim is governed by 112 ¶ 6, sufficient structure exists in the specification.		

No.	'435 Patent Terms	Plaintiff's Proposed Construction	Defendants' Proposed Construction
16.	1. A portable cell phone, comprising: a power circuit that provides a network adjusted transmit power level as a function of a **position to a communications tower**; and a proximity regulation system, including: a location sensing subsystem that determines a location of said portable cell phone proximate a user; and	**Construction:** "transmit signal strength of a communications path between the communications tower and the portable cell phone" **Intrinsic Evidence:** '435 at Col. 3:39-42. "Mobile Communications Engineering: Theory and Applications" by William C. Lee,	**Construction:** plain and ordinary meaning, no construction necessary <u>**Intrinsic Support:**</u> <u>Claims:</u> '435 Patent: Claim 1.

Appendix B: Joint Claim Construction Chart

No.	'435 Patent Terms	Plaintiff's Proposed Construction	Defendants' Proposed Construction
	a power governing subsystem, coupled to said location sensing subsystem, that determines a proximity transmit power level of said portable cell phone based on said location and determines a transmit power level for said portable cell phone based on said network adjusted transmit power level and said proximity transmit power level.	McGraw Hill (1997), incorporated by reference, '435 at Col. 3:9-13. **Extrinsic Evidence:** K. Kagoshima, W.C.Y. Lee, K. Fujimoto, and T. Taga, *Chapter 2 Essential Techniques in Mobile Antenna Systems Design, in* MOBILE ANTENNA SYSTEMS HANDBOOK, 23, 35-48 (K. Fujimoto & J.R. James, eds.) (2d ed. 2001). *See* BNR-SDCA00037949-BNR-SDCA00037966. BNR also reserves the right to rely on any Intrinsic or Extrinsic Evidence that Defendants identify for this term. **Statement of Impact:** Adopting BNR's proposal for this term would ensure that the claim remains consistent with the	Figures: '435 Patent: Fig. 1. Specification: '435 Patent: 2:18-21, 3:4-6, 4:26-28, 6:33-41. Prosecution History: U.S. Patent App. No. 09/967,140, August 13, 2004 Office Action at 7-8; November 18, 2004 Applicant Remarks/Arguments Made in an Amendment at 9-10. **Impact of Proposed Construction:** Defendants do not believe that construction is necessary in that the jury will not benefit from deviating from the established plain and ordinary meaning of "position to a communications tower." However, BNR contends that the term "position to a communications

Appendix B: Joint Claim Construction Chart

No.	'435 Patent Terms	Plaintiff's Proposed Construction	Defendants' Proposed Construction
		specification, other claims, and the surrounding claim language. It would further serve to limit the potential application or relevance of one or more prior art references identified and relied upon by Defendants with respect to the '435 Patent.	tower" requires construction. While Defendants do not believe a construction of "position to a communications tower" will impact the alleged infringement, BNR contends that this term has a specific construction that would have an impact on infringement.

Additional Indefinite Terms

No.	Term	Plaintiff's Statement	Defendants' Statement
	<u>'889 Patent:</u> 1. A mobile station, comprising: a display; a proximity sensor adapted to generate a signal indicative of proximity of an external object; and a microprocessor adapted to: (a) determine whether a telephone call is active;	Not indefinite. BNR will oppose Defendants' motion on indefiniteness and will submit its evidence at that time, as contemplated by the Court's order and the applicable rules of motion practice.	**Construction:** indefinite **<u>Intrinsic Support:</u>** <u>Claims:</u> '889 Patent: Claims 1, 8; '554 Patent: Claims 7, 13.

Appendix B: Joint Claim Construction Chart

No.	Term	Plaintiff's Statement	Defendants' Statement
	(b) receive the signal from the proximity sensor; and (c) reduce power to the display if (i) the microprocessor determines that a telephone call is active and (ii) the signal indicates the proximity of the external object; wherein: the telephone call is a wireless telephone call; the microprocessor reduces power to the display while the signal indicates the proximity of the external object only if the microprocessor determines that the wireless telephone call is active; and the proximity sensor begins detecting whether an external object is proximate **substantially concurrently** with the mobile station initiating an outgoing wireless telephone call or receiving an incoming wireless telephone call. 8. A method of conserving battery power in a mobile station, comprising:		**Extrinsic Support:** Defendants may rely on expert opinion from Dr. Paul Min regarding the technology background and the state of the art relating to these patents, and/or to establish the understanding of the term by a person of ordinary skill in the art at the time of the alleged inventions, *e.g.*, how the patents' claims, viewed in light of the specification and prosecution inform those skilled in the art about the scope of the term. Dr. Min may also provide expert opinion rebutting BNR's or its expert's constructions or opinions. **Statement of Impact:** Finding this term indefinite would render all asserted claims 1, 2, 4, 5, 6, 8, 12 of the '889 Patent and asserted claim 7 of the '554 Patent invalid.

Appendix B: Joint Claim Construction Chart

No.	Term	Plaintiff's Statement	Defendants' Statement
	detecting whether an external object is proximate; determining whether a telephone call is active; and reducing power consumption of a display of the mobile station if (i) a telephone call is determined to be active and (ii) the proximity of the external object is detected; wherein: the telephone call is a wireless telephone call; the power consumption of the display is reduced while the proximity of the external object is detected only if the wireless telephone call is determined to be active; and detecting whether an external object is proximate begins **substantially concurrently** with the mobile station initiating an outgoing wireless telephone call or receiving an incoming wireless telephone call. ’554 Patent:		

Appendix B: Joint Claim Construction Chart

No.	Term	Plaintiff's Statement	Defendants' Statement
	7. The mobile station as recited in claim 1, wherein the proximity sensor begins detecting whether an external object is proximate **substantially concurrently** with the mobile station initiating an outgoing telephone call. 13. The method as recited in claim 8, wherein the detecting whether an external object is proximate begins **substantially concurrently** with the mobile station initiating an outgoing telephone call.		
	’889 Patent: 1. **A mobile station, comprising:** a display; a proximity sensor adapted to generate a signal indicative of proximity of an external object; and a microprocessor adapted to: (a) determine whether a telephone call is active; (b) receive the signal from the proximity sensor; and	Not indefinite. BNR will oppose Defendants’ motion on indefiniteness and will submit its evidence at that time, as contemplated by the Court’s order and the applicable rules of motion practice.	**Construction:** indefinite **Intrinsic Support:** Claims: ’889 Patent: Claim 1. **Statement of Impact:** Finding this term indefinite would render asserted claims 1, 2, 4, 5, and 6 of the ’889 Patent invalid.

Appendix B: Joint Claim Construction Chart

No.	Term	Plaintiff's Statement	Defendants' Statement
	(c) reduce power to the display if (i) the microprocessor determines that a telephone call is active and (ii) the signal indicates the proximity of the external object; wherein: the telephone call is a wireless telephone call; the microprocessor reduces power to the display while the signal indicates the proximity of the external object only if the microprocessor determines that the wireless telephone call is active; and **the proximity sensor begins detecting whether an external object is proximate substantially concurrently with the mobile station initiating an outgoing wireless telephone call or receiving an incoming wireless telephone call.**		
	’842 Patent: 1. A wireless communications device, comprising:	Not indefinite. BNR will oppose Defendants’ motion on indefiniteness and will submit its evidence at that time, as contemplated by the Court’s order	**Construction:** Indefinite

Appendix B: Joint Claim Construction Chart

No.	Term	Plaintiff's Statement	Defendants' Statement
	a signal generator that generates an extended long training sequence; and an Inverse Fourier Transformer operatively coupled to the signal generator, wherein the Inverse Fourier Transformer processes the extended long training sequence from the signal generator and provides an **optimal extended long training sequence** with a minimal peak-to-average ratio, and wherein at least the **optimal extended long training sequence** is carried by a greater number of subcarriers than a standard wireless networking configuration for an Orthogonal Frequency Division Multiplexing scheme. 4. The wireless communications device according to claim 2, wherein the **optimal extended long training sequence** has a minimum peak-to-average power ratio of 3.6 dB.	and the applicable rules of motion practice.	**Extrinsic Support:** Defendants may rely on expert opinion from Dr. Jonathan Wells and/or Dr. Paul Min regarding the technology background and the state of the art relating to this patent, and/or to establish the understanding of the term by a person of ordinary skill in the art at the time of the alleged inventions, *e.g.*, how the patent's claims, viewed in light of the specification and prosecution inform those skilled in the art about the scope of the term. Dr. Wells and/or Dr. Min may also provide expert opinion rebutting BNR's or its expert's constructions or opinions. **Impact of Proposed Construction:** Finding this term indefinite would render all asserted claims 1, 3, 4, 8, 11, 14, and 19 of the '842 Patent invalid.

Appendix B: Joint Claim Construction Chart

No.	Term	Plaintiff's Statement	Defendants' Statement
	14. The wireless communications device according to claim 1, wherein the **optimal extended long training sequence** is longer than a long training sequence used by a legacy wireless local area network device in accordance with a legacy wireless networking protocol standard.		

EXHIBIT B

UNITED STATES DISTRICT COURT
SOUTHERN DISTRICT OF CALIFORNIA
BEFORE HONORABLE CATHY ANN BENCIVENGO, JUDGE PRESIDING

BELL NORTHERN RESEARCH, LLC,, Plaintiff, vs. COOLPAD TECHNOLOGIES, INC. AND YULONG COMPUTER COMMUNICATIONS, Defendants.	CASE NO. 18CV1783-CAB-BLM SAN DIEGO, CALIFORNIA FRIDAY, APRIL 26, 2019
BELL NORTHERN RESEARCH, LLC, Plaintiff, vs. HUAWEI TECHNOLOGIES Co., LTD., HUAWEI DEVICE (HONG KONG) CO., LTD., and HUAWEI DEVICE USA, INC., Defendants.	CASE NO. 18CV1784-CAB-BLM
BELL NORTHERN RESEARCH, LLC., Plaintiff, vs. KYOCERA CORPORATION and KYOCERA INTERNATIONAL INC., Defendants.	CASE NO. 18CV1785-CAB-BLM
BELL NORTHERN RESEARCH, LLC., Plaintiff, vs. ZTE CORPORATION, ZTE (USA) INC. ZTE (TX) INC. Defendants.	CASE NO. 18CV1786-CAB-BLM

BELL NORTHERN RESEARCH, LLC,,)
)
Plaintiff,) CASE NO. 18CV2864-CAB-BLM
)
vs.)
)
LG ELECTRONICS, INC., LG)
ELECTRONICS U.S.A. INC., and)
LG ELECTRONICS MOBILE RESEARCH)
U.S.A., LLC,)
)
Defendants.)
________________________________)

REPORTER'S TRANSCRIPT OF PROCEEDINGS
STATUS HEARING
PAGES 1-21

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Proceedings reported by stenography, transcript produced by computer assisted software

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Federal Official Court Reporter
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San Diego, California; Friday, April 26, 2019; 2:00 p.m.

(Matter No. 14 called)

MS. ABDULLAH: Good afternoon, your Honor. Sadef Abullah from Skiermont Derby on behalf of plaintiff, BNR.

MR. HARTSELL: Good afternoon, your Honor. Stephen Hartsell also here with Skiermont on behalf of BNR.

THE COURT: Thank you.

MR. MILLIKEN: Tom Milliken and James Hurt from Perkins Coie, your Honor.

(Matter No. 15 called)

MS. FULLER: Joanna Fuller here on behalf of Huawei. With me is Michael Sobolev.

(Matter No. 16 called)

MR. WITCOFF: Good afternoon, your Honor. David Witcoff on behalf of the Kyocera defendants.

(Matter No. 17 called)

MS. ZHANG: Good afternoon, your Honor. Jiaxiao Zhang in person for the ZTE defendants, and on the phone is Charles McMahon.

MR. McMAHON: Good afternoon, your Honor.

THE COURT: Thank you.

(Matter No. 18 called)

MS. FULLER: In person is Joanna Fuller. On the phone, we have Mr. Michael McKeon and Mr. Steve Marshall.

THE COURT: Thank you. This is a status to help the

Court prepare for the claim construction and to address some matters that were raised by the parties in your joint claim construction hearing statement; as well as, I want to hear on the newest case, the '2864 case, with LG. They're not right now consolidated into this case and if they want to be, there are two new patents in that case. And so while they could be added to the existing case, I would probably be looking at scheduling a claim construction on any issues raised on those two patents at a future date. So why don't we deal with that.

So in terms of, Ms. Fuller and Mr. Marshall and Mr. McKeon, what do you want to do on that?

MR. McKEON: Good afternoon, your Honor. Mike McKeon on behalf of LG. Our preference, your Honor -- as you know, on the schedule, we just answered nine days ago, so we're very much behind here.

THE COURT: Yes.

MR. McKEON: So our preference, of course, would be not to consolidate it and to have a separate track. And of course, we recognize that as a practical matter on the patents where there's an overlap -- and my understanding is there is an overlap on four patents -- your Honor's rulings on those would, again, as a practical matter, be held to LG. But what we would ask is we would be on a separate track and on the two patents that don't overlap, we would have a separate process on those. And to the extent there were particular terms in the four patents where we had the overlap -- or the six patents rather, I should say, where we had an overlap, LG would be able to raise those terms that impacted us in particular in that process that we had.

So we recommend a separate process, a separate track focusing on the two patents and any additional terms that were particularly relevant for LG on the sixth patent, and then, of course, on the terms that your Honor deals with in the other cases, we would recognize that that would be something that we would be held to.

THE COURT: All right. That sounds reasonable.

Plaintiffs.

MS. ABDULLAH: Your Honor, we're fine with that approach. You know, it's our preference that we not slow down the currently pending cases given that there has been some work done, so we're fine with LG being on a separate track and with a claim construction hearing as what Mr. McKeon just described.

THE COURT: All right. And I believe you have an ENE scheduled.

MS. ABDULLAH: That's right, your Honor, for the end of May.

THE COURT: I will talk with Judge Major on that in terms of setting a claim construction case management schedule in the LG matter separately. And, yes, in terms of the three patents, there's three right now that are currently, as I understand it, where claim constructions have been submitted, the '156, the '862, and the '450. To the extent that the Court construes claims in those matters, you would have to give me compelling reasons to revisit those claim constructions with regard to the LG case. Generally they will be persuasively carried over throughout the litigation. However, if there are claim terms that you determine that you think are significant to your accused devices that are not covered in the constructions that I'm dealing with, then, yes, you would be able to introduce additional terms to be construed in those three patents.

So we'll go ahead then and I'll leave LG not consolidated and we'll get that case on a separate track so the four consolidated cases can continue to go forward.

So then returning to the claim construction, I have received your proposed chart and worksheet, and as I understand it, there are three patents, again, the '862, the '450, and the '156, for which the parties have jointly submitted claims to be construed. I did not see any claims offered for the '889, the '554, the '842, the '432, and the '435. But that might have to do with your indefiniteness issues that are raised sort of as a sideshow here.

MS. ABDULLAH: I'm sorry, your Honor. I think there are additional terms actually. I believe the '889 and '554 as well as the '435, and then for the '842, there's at least one that doesn't have to do with indefiniteness.

THE COURT: Well, the materials, unless they're in different cases, because I only -- I pulled the worksheet up and I've got claim terms from the '862, the '450, the '156 -- oh, okay. Wait a minute. No. Yes, the '156 and the -- yes. Are those numbers just wrong on the top?

MS. ABDULLAH: Your Honor, I'm not really sure. I apologize.

THE COURT: I'm looking at document 63. And so the first set of terms are from claim 9 of the '862, and then there's another reference to the '862 in claim 10. Is that just an error?

MS. ABDULLAH: I apologize. So your Honor, the joint hearing statement lists the ten most important terms that the parties have identified, so the full list is identified in appendices A and B. I apologize for not being clear on that.

THE COURT: Oh, okay. I didn't understand that to be a summary. I understood that to be the terms you were asserting. Okay. That's fine. So there's a total then of 15 terms.

MS. ABDULLAH: I think we -- depending on how you count some of them, there might be up to 17 that have some sort of claim construction issue raised. So it does exceed 15 by a couple, or possibly one, depending on how you view it. It was BNR's position there was no need to exceed 15, but the defendants did feel the need to do so. So I think in the end, if the Court is okay with it and if the defendants are requesting it, we're not going to oppose that request.

THE COURT: I can live with 17. It's not the end of the world. So if in the appendices it's 17 terms or phrases, that's fine. We'll proceed with that. So I'll go back and look at that again and organize that in a way that is more clear to me.

Okay. Then the only other issue I had was with regard to a clarification on my comments about indefinite arguments. So indefiniteness is part of the claim construction consideration and so it's raised in the context of claim construction usually, but it could be dispositive. So rather than just construing the claim one way or the other, which is the general result of claim construction when someone is raising an indefinite argument, and I think to carve it out for purposes of preserving appellate issues, they're more appropriately addressed in a motion that I would like filed in conjunction with the claim construction indicating that, in fact, there could be a dispositive ruling on whether or not this claim is valid.

So with the opening claim construction briefs that are due on May 24th, the defendants should identify any claim terms that they are challenging based on indefiniteness, whether or not that's because it's a 112(6) analysis that has no structure supporting it or just there's nothing in the patent that defines it. However, I don't want like 20 briefs. I want it all in one brief with the terms identified. You don't need to spend a lot of time on background because it will be covered generally in the construction of the patents. I'll just focus on what the term is, what's not present in the specification, and why a person of ordinary skill in the art wouldn't be able to figure it out. And I would like to keep that brief limited to 20 pages tops.

I don't know how many terms you're talking about, but I just got buried in another case where they filed 28 motions for summary judgment, and that's not happening in the future, just so you know. So if you file yours on the 24th with your claim construction opening brief, your response, in addition to your claim construction responses, will also be a reply brief of 15 pages in response to their indefiniteness arguments. There won't be any reply. We'll just deal with it in argument then. Is that more clear? Because I know there was confusion.

MS. FULLER: Well, I just wanted to talk through. So there's seven terms for construction, six terms that have been argued are indefinite, and six more terms that have been argued are means-plus-function, and the defendants don't all agree on the terms for all of these and so we're hoping that we could get additional pages beyond -- initially we were thinking it was 25 under the rules, and we're going to ask to maybe moving it up to 40 pages.

THE COURT: You know, it really shouldn't take 40 pages. If it's there, it's there. If it's not, it's not. If the claim can be construed, it's probably not indefinite. The problem is it can't be construed because there's nothing supporting it in the specification or generally known in the art. So I think you're going to need to figure out how you're going to present them and maybe focus on the ones that are most important and reserve perhaps on others if we need to come back and visit them, but I'm not going to do 45 pages on indefiniteness, or 40 pages. I'll give you 25 total. So try to figure it out between you which ones you think are the most significant ones to raise.

And as I've said before, even with the claim constructions, obviously I'm trying to prioritize this to get to the most important stuff. I recognize your due process rights to address your claims and defenses after the constructions issue. If you feel in light of that and other discovery that you need to raise new issues going forward, I'll accept application for additional construction on claims in the future. But generally, I've found that when people are required to focus, we get to the heart of it and there's a lot of stuff that doesn't end up being an academic exercise for the Court to figure out what a term is.

I have said this before: I am very wary of plain and ordinary meaning as a proposed construction. As one federal circuit judge said: Construction can go on indefinitely because you can construe the words that you used to construe the words to construe the words, and at some point, everyone has to reach an agreement on what a word means. It's not sufficient, for me, for you to just say "plain," particularly given the level of complexity of these patents. If there's a plain and ordinary meaning, it has to be that to a person of skill in the art.

So you have to be a little bit more specific as to what the proposed plain and ordinary meaning is beyond the words used, if necessary. It may not be necessary, but if it is, then maybe can you reach an agreement. But you guys just saying plain and ordinary meaning and then them saying something completely different isn't helpful to me.

Okay. Questions? Yes.

MR. SOBOLEV: Were you saying that it's a 25-page limit just for the separate indefiniteness briefing?

THE COURT: You need to address everything you need to address. And while I don't want you to be overly verbose, I'm not putting any limit on your claim construction briefs, just on the indefiniteness where you're focusing on that and why those particular claims might render the claim invalid.

MR. SOBOLEV: Thank you, your Honor.

MR. WITCOFF: Your Honor, can I ask one question?

THE COURT: Yes.

MR. WITCOFF: I think I understand. Just to make sure: Six of these terms, as you've heard, we contend are means-plus-function terms and we further contend they're indefinite for the lack of supporting structure. Are you contemplating we argue the means-plus-function aspect in the claims construction briefing and then argue in the separate indefiniteness briefing?

THE COURT: You can do that. If your position is it's means-plus-function and there's no means to support it, go ahead and do that in your indefiniteness brief.

MR. WITCOFF: In the indefiniteness brief. I'm just thinking about the 25 pages now.

THE COURT: Whether or not it qualifies as a 112(6), it either does or it doesn't. So I don't need the history of 112(6). Don't waste pages on the legal. I know what the legal standard is.

MR. WITCOFF: We know.

THE COURT: So focus on, you know, why you believe if the word "means" isn't used, why this is nonce word or has no meaning, and then why there's nothing in the specification that explains what it is.

MR. WITCOFF: That make sense. That way it's all in one place.

THE COURT: A lot of it can be very much done in the way it charts. Here's the claim term, here's the function, here's the only place it's mentioned in the specification, and it's just a black box. If it's that simple, then it shouldn't take a lot of pages. If it's more complicated, then there may be a bigger problem.

MR. WITCOFF: I understand. I just wanted to make sure we understood what you were saying. Thank you.

MS. ABDULLAH: Your Honor, given that they get five extra pages, we'll try to fit it in 15.

THE COURT: You get 20 now.

MS. ABDULLAH: Thank you.

THE COURT: I'll hate myself in the morning, but okay. Anything else? Okay. I have you scheduled for your claim construction on June 19th and 20th. I think you indicated you might need to spill into a third day. I, at this point, can't give you a third day in June because the 21st is normally my Friday where I do my criminal calendar. If we don't get it all done, then we'll schedule a follow-up day. I might be exhausted after two days, anyway, of this and might not even be able to do a third day. If you can work together on the tutorial and make it truly a tutorial and not a sideways advocacy thing, then maybe we can cut down some time that's needed for that.

MS. ABDULLAH: Your Honor, for claims construction, we had a proposal which patents to cover together on a day. And we did share it with defendants but I'm not sure they've responded to us yet. So if I could share that with you, we were thinking that the '842, the '862, the '450, and the '156 could go together.

THE COURT: Okay.

MS. ABDULLAH: Those are all WiFi related in some capacity, also the math patents are within that, and then the remainder, which would be the '889, the '554, the '435 and -- what am I leaving out? The '432 -- I apologize. I messed that up. The first set should be '842, '862, '450, and '432, and then the second day, whether it be first or second, would be the '156, the '435, the '889, and the '554.

THE COURT: Okay. I can't really respond to that right now.

So you've got her proposed grouping. If you think a different grouping makes more sense in terms of order of presentation, then why don't you all try to communicate on that. It would be helpful to the Court if I know what you're planning on the order of presentation by a week before just so I can organize my thoughts. If that grouping works for you, that would be fine with the Court. It breaks the patents up evenly, and it would be helpful. If they are distinctly separate in terms of subject matter, then also consider doing a tutorial just addressing the first four patents and their relationship and then start the second day on the other four patents and their relationship just so that I don't have to try to remember it overnight.

MR. WITCOFF: That's fine, your Honor. We'll discuss among ourselves, work with them, and get back to you with a joint proposal.

THE COURT: Great. Thank you.

MS. ABDULLAH: Your Honor, we do have a couple of other issues that are not, I guess, directly related to claims construction. If you would like to hear those now?

THE COURT: Well, it depends. Go ahead.

MS. ABDULLAH: So the first one, I'm going to let my colleague address the Court.

MR. HARTSELL: Good afternoon, your Honor. As you're probably aware, Judge Major a couple of days ago determined that our expert, Dr. Madisetti, cannot be an expert for ZTE.

THE COURT: That matter is still pending in front of her for consideration, isn't it?

MR. HARTSELL: Well, we've asked for clarification to understand how it impacts the consolidated -- like the claims constructions since the Court has consolidated those. And it's my understanding that ZTE believes that Dr. Madisetti shouldn't be --

THE COURT: You know what? I get it. But that's her ruling and until it's final and you can then brief it to me as a matter of appealing her ruling, although the standard is clearly erroneous, so it's pretty tough. But I'm not going to hopscotch over her and take it out of her hands. It's in her hands. I'm aware it's on the docket, but I have not read the briefs. I don't really know what the issue is. It's for her decision, so I'm not going to address that today.

MR. HARTSELL: Thank you, your Honor.

THE COURT: Anything else?

MS. ABDULLAH: One last question, your Honor, and hopefully this is just a matter of seeking clarification. In the invalidity contentions that the defendants served, your Honor had limited them to ten obviousness combinations per patent during the case management conference, and so what they have done is they've identified ten combinations of prior art, but then, in many other instances, they also say, you know, this prior art reference to the extent it doesn't disclose X limitation, a person of ordinary skill in the art would know to supply that limitation. It's our view that that should count as a combination because essentially you're combining the knowledge of the reference. The defendants have taken the opposite view. So obviously under our interpretation, they would have exceeded the ten combinations by quite a bit.

THE COURT: But it's a single reference where they're saying a missing element was something that someone of skill in the art would know?

MS. ABDULLAH: Yes, basically.

THE COURT: I'm not going it prohibit that. You know what the reference is, and how do -- this isn't like pull from this and pull from that. They're making an assertion that someone would know it. Obviously, at some point, they'll have to support that. And there's really not a whole lot. It's not like you have to go read something.

MS. ABDULLAH: In some of the cases, they actually did cite another article or two showing what a person of skill in the art would know. It's kind of unclear. They're not directly relying on that reference, but then they're relying on the knowledge which is shown by that reference, so.

THE COURT: The limitations are designed to keep this from becoming just a flood of unnecessary paperwork that's exchanged between the parties. And at some point, obviously if the case proceeds first to summary judgment and then to trial, they're not going to put on a hundred different prior art references. So trying to give people the top ten combinations to start with is my intent to try to focus people. But I've also told them if they have art that they think is relevant, they need to identify it so they could potentially use it later if they have to adjust their combinations in light of claim construction and other things.

At this point, I appreciate your concern. I think it's a little premature. I think after the claim construction, there will be an opportunity again to focus on the invalidity arguments and prior art combinations they want to make, and maybe we can look at those combinations again and address your issue.

I understand the concern, but I'm not precluding it right now if it's simply really just identifying art that's out there and saying any missing element, somebody would have understood, and if it's backed up by a written -- I mean, that is a combination if you're using a written document to support the missing element, but it's not quite the same as here is one patent and another patent and you have to put them together to get all the pieces. I hear what you're saying, but we'll address those issues again, both the number of asserted claims and the number of prior art references, after the claim construction is issued.

MS. ABDULLAH: Thank you, your Honor.

THE COURT: Anything else? Otherwise discovery is moving along? Everything is good? Okay, good. Great.

The only other thing that -- it's in the rules, but the sooner the better, if you can get a glossary of terms to my court reporter, it is of tremendous assistance to her that she can put those things into the computer before the hearing so she has a leg up on trying to keep up while you guys are talking. So if you have -- there's a lot of technical terms here, so it would be helpful if you could get those to Mauralee. Good. Okay.

For the show and tell of the claim construction, I need a hard copy of anything you're going to project. If you're going to do any kind of Power Point, please make sure the pages are numbered in case we have to skip around so I can keep up and find out where you are. Just a set for me, and if you want to give us a second set on a thumb drive or something for my law clerk to keep for the records, that's fine. I don't need multiple copies. Actually give one to me and one to the court reporter, because it's also helpful for her to have it later when she's working on the transcript to refer back. Okay. Great. Look forward to seeing you all in June. Thank you.

MS. ABDULLAH: Thank you, your Honor.

(Court in recess at 2:30 p.m.)

**** End of requested transcript ****

CERTIFICATE OF OFFICIAL REPORTER

I, Mauralee Ramirez, Federal official Court Reporter, in and for the United States District Court for the Southern District of California, do hereby certify that pursuant to Section 753, Title 28, United States Code that the foregoing is a true and correct transcript of the stenographically reported proceedings held in the above-entitled matter and that the transcript page format is in conformance with the regulations of the Judicial Conference of the United States.

Dated this 3rd day of May 2019.

/S/ Mauralee Ramirez
Mauralee Ramirez, CSR No. 11674, RPR
Federal Official Court Reporter

EXHIBIT C

UNITED STATES DISTRICT COURT

SOUTHERN DISTRICT OF CALIFORNIA

BELL NORTHERN RESEARCH, LLC, Plaintiff, v. COOLPAD TECHNOLOGIES, INC. AND YULONG COMPUTER COMMUNICATIONS, Defendants.	Case No. 3:18-cv-01783-CAB-BLM [LEAD CASE]
BELL NORTHERN RESEARCH, LLC, Plaintiff, v. HUAWEI DEVICE (DONGGUAN) CO., LTD., HUAWEI DEVICE (SHENZHEN) CO., LTD., and HUAWEI DEVICE USA, INC., Defendants.	Case No. 3:18-cv-01784-CAB-BLM

BELL NORTHERN RESEARCH, LLC, Plaintiff, v. KYOCERA CORPORATION and KYOCERA INTERNATIONAL INC., Defendants.	Case No. 3:18-cv-01785-CAB-BLM
BELL NORTHERN RESEARCH, LLC, Plaintiff, v. ZTE CORPORATION, ZTE (USA) INC., ZTE (TX) INC., Defendants.	Case No. 3:18-cv-01786-CAB-BLM

DECLARATION OF PAUL MIN, PH.D.
REGARDING CLAIM CONSTRUCTION

I certify under penalty of perjury that the following is true and correct.

Date: May 1, 2019 By: ____________________

Paul Min, Ph.D.

TABLE OF CONTENTS

PAGE

I. Introduction

1. My name is Paul Min, Ph.D. I am a Senior Professor of Electrical and Systems Engineering at Washington University in St. Louis, Missouri. I am over the age of twenty-one, competent to make this declaration, and have personal knowledge of the matters stated herein.

2. I have been retained on behalf of Defendants Kyocera Corporation and Kyocera International Inc. ("Kyocera Defendants) to opine on and provide expert testimony related to: (i) U.S. Patent No. 6,941,156 ("the '156 Patent") (attached as Exhibit C), and (ii) U.S. Patent No. 7,957,450 ("the '450 Patent") (attached as Exhibit D), and (iii) U.S. Patent No. 8,416,862 ("the '862 Patent") (attached as Exhibit E). I understand that my opinions and expert testimony are also relevant to proceedings involving one or more of these three patents with respect to Defendants Coolpad Technologies, Inc. and Yulong Computer Communications ("Coolpad Defendants"); Huawei Device (Dongguan) Co., Ltd., Huawei Device (Shenzhen) Co., Ltd., Huawei Device USA, Inc., ("Huawei Defendants"); and ZTE Corporation, ZTE (USA) Inc., and ZTE (TX) Inc. ("ZTE Defendants"), whose cases have been consolidated with the Kyocera Defendants for claim construction purposes. For purposes of this statement, the term "Defendants" is used to generally refer to the Kyocera Defendants, Coolpad Defendants, Huawei Defendants, and ZTE Defendants.

3. In this declaration, I opine on the scope and meaning of certain terms that appear in the '156 Patent, '450 Patent, and '862 Patent, which I collectively refer to as the "Patents-in-Suit."

4. In this declaration, I also opine on the level of ordinary skill in the art for the Patents-in-Suit, which is relevant to understanding how a person of ordinary

skill in the art ("POSITA") would understand the scope and meaning of the claims of those patents.

5. In this declaration, I also provide an overview of the Patents-in-Suit, as well as the technology and field of art as of the filing date of each of those patents.

6. To prepare this declaration, I have considered the documents and information set forth in Exhibit B.

7. This declaration is based on the information currently available to me. To the extent additional information becomes available, I reserve the right to amend and supplement this statement and my analysis and opinions. In particular, my understanding is that BNR has disclosed Dr. Vijay Madisetti as an expert witness who may opine on the '156 Patent, '450 Patent, and '862 Patent. To date, I have not received or reviewed any testimony, analysis, or opinions of Dr. Madisetti regarding these patents. To the extent that Dr. Madisetti, or any other expert, provides testimony or evidence related to the scope and meaning of the '156 Patent, '450 Patent, and '862 Patent, or to the extent that BNR amends its proposed constructions, I reserve the right to review and respond.

8. My understanding is that the Court will hold a claim construction hearing. If I am called upon to testify at this hearing or any other proceeding about this statement, including at deposition, I may cite other documents or information similar to that specifically identified in this statement. I may also use graphics, animations, pictures, demonstrations, and/or other audio/visual aids to explain my analysis and opinions.

9. For my time spent in connection with this declaration, I will be compensated in the amount of $450 per hour. My compensation does not depend on the outcome of this case.

II. Summary of Opinions

A. Summary of Opinions Regarding the ’156 Patent

10. My understanding is that BNR and the Defendants dispute the scope and meaning of claim terms that appear in claim 1 of the ’156 Patent.

11. In my opinion, Defendants’ proposed construction is correct, for the reasons discussed in this declaration, with respect to the term “simultaneous communication paths from said multimode cell phone.” In my opinion, the remaining terms—“cell phone functionality,” “RF communication functionality,” and the two “module” terms—are indefinite means-plus-function terms, for the reasons discussed in this declaration. The parties’ proposed constructions are shown in the table below.

’156 Patent Claim Term	BNR’s Proposed Construction	Defendants’ Proposed Construction
“simultaneous communication paths from said multimode cell phone”	Plain and ordinary meaning. In the alternative, to the extent the Court determines that a specific construction is warranted, BNR proposes: “two or more active links at the same time from said multimode cellphone”	“at least two established distinct and different communication links from said multimode cell phone to a far-end communication device, at the same time”
“cell phone functionality”	Not a 112 ¶ 6 claim element – “cell phone functionality” is not a nonce word. Instead, cell phone functionality is itself sufficient structure. A POSA would know this is a cellular RF communication	This is a 112 ¶ 6 claim element. <u>Function:</u> “cell phone” <u>Structure:</u> Indefinite for lack of corresponding structure in the patent specification.

'156 Patent Claim Term	**BNR's Proposed Construction**	**Defendants' Proposed Construction**
	functionality well known in the art.	Huawei and Coolpad Defendants state alternatively, to the extent that the Court requires an identification of structure, the cell phone 100a and corresponding antenna depicted in Fig. 1 are insufficient structure to perform the claimed function.
"RF communication functionality"	Not a 112 ¶ 6 claim element – "RF communication functionality" is not a nonce word. Instead, RF communication functionality is itself sufficient structure. A POSA would know this is a structure for RF communications through a genus of RF communication types well known in the art.	This is a 112 ¶ 6 claim element. Function: "RF communication" Structure: Indefinite for lack of corresponding structure in the patent specification. Huawei and Coolpad Defendants state alternatively, to the extent that the Court requires an identification of structure, any of the cordless phone 100b with its corresponding antenna and the walkie-talkie 100c with its corresponding antenna, are insufficient structure to perform the claimed function.

’156 Patent Claim Term	BNR’s Proposed Construction	Defendants’ Proposed Construction
“a module to establish simultaneous communication paths from said multimode cell phone using both said cell phone functionality and said RF communication functionality”	Not a 112 ¶ 6 claim element – “module” is not a nonce word here. Instead, the “module to establish simultaneous communication paths from said multimode cell phone using both said cell phone functionality and said RF communication functionality” is itself sufficient structure. A POSA would know this is a structure for RF communications through a genus of RF communication types well known in the art. In the alternative, to the extent the Court determines that this claim is governed by 112 ¶ 6, BNR proposes the following Function and Structure, and disagrees that the term is indefinite for lack of corresponding structure: <u>Function</u>: establish simultaneous communication paths from said multimode cell phone using both said cell phone functionality and said RF	This is a 112 ¶ 6 claim element. <u>Function</u>: “establish simultaneous communication paths from said multimode cell phone using both said cell phone functionality and

'156 Patent Claim Term	BNR's Proposed Construction	Defendants' Proposed Construction
	communication functionality Structure: Corresponding structure for the alleged function exists in at least the following portions of the patent specification, or their equivalents: Figs. 1, 3, Col. 3:48–4:49; 4:54–5:62; 6:3–55; 6:60–8:5	said RF communication functionality" Kyocera & ZTE propose: Structure: Indefinite for lack of corresponding structure in the patent specification. Huawei & Coolpad propose: Structure: Fig. 1 (element 101); Fig. 2 steps 202-208; Fig. 4 steps 402-408; 4:50-67; 7:1-16.
"an automatic switch over module, in communication with both said cell phone functionality and said RF communication functionality, operable to switch a communication path established on one of said cell phone functionality and said RF communication functionality, with another	Not a 112 ¶ 6 claim element – "module" is not a nonce word here. Instead, the "an automatic switch over module, in communication with both said cell phone functionality and said RF communication functionality, operable to switch a communication path established on one of said cell phone functionality and said RF communication functionality, with another communication path later established on the other of	This is a 112 ¶ 6 claim element.

'156 Patent Claim Term	BNR's Proposed Construction	Defendants' Proposed Construction
communication path later established on the other of said cell phone functionality and said RF communication functionality"	said cell phone functionality and said RF communication functionality" is itself sufficient structure. A POSA would know this is a structure for RF communications through a genus of RF communication types well known in the art. In the alternative, to the extent the Court determines that this claim is governed by 112 ¶ 6, BNR proposes the following Function and Structure, and disagrees that the term is indefinite for lack of corresponding structure: <u>Function:</u> in communication with both said cell phone functionality and said RF communication functionality, operable to switch a communication path established on one of said cell phone functionality and said RF communication functionality, with another	Kyocera & ZTE propose: <u>Function</u>: "in communication with both said cell phone functionality and said RF communication functionality, operable to switch a communication path established on one of said cell phone functionality and said RF communication functionality, with another communication path later established on the other of said cell phone functionality and said RF communication functionality" <u>Structure</u>: Indefinite for lack of corresponding structure in the patent specification.

'156 Patent Claim Term	BNR's Proposed Construction	Defendants' Proposed Construction
	communication path later established on the other of said cell phone functionality and said RF communication functionality <u>Structure</u>: Corresponding structure for the alleged function exists in at least the following portions of the patent specification, or their equivalents: Figs. 1, 3, Col. 3:48–4:49; 4:54–5:62; 6:3–55; 6:60–8:5	Huawei & Coolpad propose: Function: "automatic switch over of a communication path established on one of said cell phone functionality and said RF communication functionality, with another communication path later established on the other of said cell phone functionality and said RF communication functionality" <u>Structure:</u> Fig. 1 (element 101); Fig. 2 steps 210-212; Fig. 4 steps 410-412; 5:1-7; 7:17-26, claim 1 ("an automatic switch over module, in communication with both said cell phone functionality and said RF communication functionality").

Joint Claim Construction Worksheet, Appendix A at 34–47.

12. I understand the earliest priority date for the '156 Patent is June 26, 2001, the date the application for the '156 Patent was filed, or it may be on or after August 1, 2000, a date BNR states that it may allege the claimed invention was conceived and then followed by a diligent reduction to practice. *See* BNR's Patent L.R. 3.6 Amended Disclosure of Asserted Claims and Infringement Contentions,

section F (April 19, 2019). Independent of whether the earliest priority date is August 1, 2000, or June 26, 2001, or a date in-between, it is my opinion that a POSITA for the ’156 Patent would have had a Bachelor’s degree in Electrical Engineering, Computer Engineering, Computer Science, or a related field, and at least 2 years of experience in the field of wireless communication, or be a person with equivalent education, work, or experience in this field by the earliest priority date.

B. Summary of Opinions Regarding the ’450 Patent

13. My understanding is that BNR and the Defendants dispute the scope and meaning of claim terms that appear in claims 1–3, 11–13, 21, and 22 of the ’450 Patent.

14. In my opinion, Defendants’ proposed constructions are correct, for the reasons discussed in this declaration. The parties’ proposed constructions are as follows:

’450 Patent Claim Term	BNR’s Proposed Construction	Defendants’ Proposed Construction
“channel estimate matrices”; “matrix based on the/said plurality of channel estimates”	Plain and ordinary meaning. In the alternative, to the extent the Court determines that a specific construction is warranted, BNR proposes: “one or more matrices that is based on an SVD decomposition of the estimates of the values of H(t)”	“matrix H_{est} for tones of different frequencies, where H_{est} contains estimates of the true values of H(t)”

’450 Patent Claim Term	BNR’s Proposed Construction	Defendants’ Proposed Construction
“coefficients derived from performing a singular value matrix decomposition (SVD)”; “coefficients from performing a singular value matrix decomposition (SVD)”	Plain and ordinary meaning. In the alternative, to the extent the Court determines that a specific construction is warranted, BNR proposes: “values derived from a singular value decomposition”	“values in the matrices U, S, or V^H, where H_{est}=USV^H”

Joint Claim Construction Worksheet, Appendix A at 22–33.

15. I understand the earliest potential priority date for the ’450 Patent is December 14, 2004, the date a provisional application was filed to which the ’450 Patent claims priority. It is my opinion that a POSITA for the ’450 Patent at the time of this earliest filing date would have had a Bachelor’s degree in Electrical Engineering, Computer Engineering, Computer Science, or a related field, and at least 2 to 4 years of experience in the field of wireless communication, or a person with equivalent education, work, or experience in this field.

C. Summary of Opinions Regarding the ’862 Patent

16. My understanding is that BNR and the Defendants dispute the scope and meaning of claim terms that appear in claims 9 and 10 of the ’862 Patent.

17. In my opinion, Defendants’ proposed constructions are correct, for the reasons discussed in this declaration. The parties’ proposed constructions are shown in the table below.

’862 Patent Claim Term	BNR’s Proposed Construction	Defendants’ Proposed Construction
“decompose the estimated transmitter beamforming unitary matrix (V) to produce the transmitter beamforming information”	“factor the estimated transmitter beamforming unitary matrix (V) to produce a reduced number of quantized coefficients”	“factor the estimated transmitter beamforming unitary matrix (V) to produce a reduced set of angles”
“a baseband processing module operable to: receive a preamble sequence carried by the baseband signal; estimate a channel response based upon the preamble sequence; determine an estimated transmitter beamforming unitary matrix (V) based upon the channel response and a receiver beamforming unitary matrix (U); decompose the estimated transmitter beamforming unitary matrix (V) to produce the	Not a 112 ¶ 6 claim element – “baseband processing module” is not a nonce word. Instead, a baseband processing module is itself sufficient structure. A POSA would know this is a baseband processor implemented in ASIC, FGPA, logic circuits, or the like in RF communication hardware. In the alternative, to the extent the Court determines that this claim is governed by 112 ¶ 6, BNR proposes the following Function and Structure, and disagrees that the term is indefinite for lack of corresponding structure: <u>Function</u>:	This is a 112 ¶ 6 claim element. <u>Function</u>: “receive a preamble sequence carried by the baseband signal;

'862 Patent Claim Term	BNR's Proposed Construction	Defendants' Proposed Construction
transmitter beamforming information; and form a baseband signal employed by the plurality of RF components to wirelessly send the transmitter beamforming information to the transmitting wireless device"	"receive a preamble sequence carried by the baseband signal; estimate a channel response based upon the preamble sequence; determine an estimated transmitter beamforming unitary matrix (V) based upon the channel response and a receiver beamforming unitary matrix (U); decompose the estimated transmitter beamforming unitary matrix (V) to produce the transmitter beamforming information; and form a baseband signal employed by the plurality of RF components to wirelessly send the transmitter beamforming information to the transmitting wireless device" <u>Structure</u>: Corresponding structure for the alleged function exists in at least the following portions of the patent specification, or their equivalents:	estimate a channel response based upon the preamble sequence; determine an estimated transmitter beamforming unitary matrix (V) based upon the channel response and a receiver beamforming unitary matrix (U); decompose the estimated transmitter beamforming unitary matrix (V) to produce the transmitter beamforming information; and form a baseband signal employed by the plurality of RF components to wirelessly send the transmitter beamforming information to the transmitting wireless device" <u>Structure</u>: Indefinite for lack of corresponding structure in the patent specification.

’862 Patent Claim Term	BNR’s Proposed Construction	Defendants’ Proposed Construction
	Figs. 2-5, Col. 5:49–6:12, 6:37–7:20; 7:51–9:30; 9:31–13:35; 13:54–15:67.	
“the baseband processing module is operable to: produce the estimated transmitter beamforming unitary matrix (V) in Cartesian coordinates; and convert the estimated transmitter beamforming unitary matrix (V) to polar coordinates”	Not a 112 ¶ 6 claim element – “baseband processing module” is not a nonce word. Instead, a baseband processing module is itself sufficient structure. A POSA would know this is a baseband processor implemented in ASIC, FGPA, logic circuits, or the like in RF communication hardware. In the alternative, to the extent the Court determines that this claim is governed by 112 ¶ 6, BNR proposes the following Function and Structure, and disagrees that the term is indefinite for lack of corresponding structure: <u>Function</u>: “a baseband processing module operable to . . . produce the estimated transmitter beamforming unitary matrix (V) in Cartesian coordinates; and convert the estimated transmitter beamforming	This is a 112 ¶ 6 claim element. <u>Function</u>: “a baseband processing module operable to . . . produce the estimated transmitter beamforming unitary matrix (V) in Cartesian coordinates; and convert the estimated transmitter beamforming

’862 Patent Claim Term	BNR’s Proposed Construction	Defendants’ Proposed Construction
	unitary matrix (V) to polar coordinates” Structure: Corresponding structure for the alleged function exists in at least the following portions of the patent specification, or their equivalents: Figs. 2-5, Col. 5:49–6:12, 6:37–7:20; 7:51–9:30; 9:31–13:35; 13:54–15:67.	unitary matrix (V) to polar coordinates” Structure: Indefinite for lack of corresponding structure in the patent specification.

Joint Claim Construction Worksheet, Appendix A at 14–21.

18. I understand the earliest potential priority date for the ’862 Patent is April 21, 2005, the date a provisional application was filed to which the ’862 Patent claims priority. It is my opinion that a POSITA for the ’862 Patent at the time of this earliest filing date would have had a Bachelor’s degree in Electrical Engineering, Computer Engineering, Computer Science, or a related field, and at least 2 to 4 years of experience in the field of wireless communication, or a person with equivalent education, work, or experience in this field.

III. Qualifications

19. I summarize in this section my educational background, career history, publications, and other relevant qualifications. My full curriculum vitae is attached as Exhibit A to this statement.

20. I received a B.S. degree in Electrical Engineering in 1982, an M.S. degree in Electrical Engineering in 1984, and a Ph.D. degree in Electrical

Engineering in 1987 from the University of Michigan in Ann Arbor. I received several academic honors, including my B.S. degree with honors, a best graduate student award and a best teaching assistant award during my M.S. study, and a best paper award from a major international conference for reporting results from my Ph.D. thesis.

21. After receiving my Ph.D., I worked at Bellcore in New Jersey from August 1987 until August 1990. At Bellcore, I was responsible for evolving the public switched telephone network (PSTN) into a multi-services voice and data network that incorporated packet switches, optical technologies, and wireless technologies.

22. In September 1990, I joined the faculty at Washington University in St. Louis. In July 1996, I was promoted to an Associate Professor of Electrical Engineering with tenure. I am currently a Senior Professor of Electrical and Systems Engineering at Washington University. I have also served as the Chair of the Graduate Curriculum (2000-2002) and the Chair of the Undergraduate Curriculum (2011-2014) for the Department of Electrical and Systems Engineering.

23. At Washington University, I have conducted research in communication, computing, and related electronic hardware and software. My research group has pioneered a new paradigm for designing electronic circuits that can alleviate the speed and performance mismatch against optical technology. I have received several grants from U.S. Federal Agencies, including the National Science Foundation and the Defense Advanced Research Project Agency, and numerous contracts from companies and organizations around the world.

24. Specifically related to the technology matters in this litigation, I have researched a variety of wireless communication technologies, including TDMA,

CDMA, WCDMA, OFDM, FDD, SC-FDMA, and TDD. I have an extensive background and experience in each of these technologies.

25. As a faculty member at Washington University, I have taught a number of courses in electronics, communication, and computing at both the undergraduate and graduate levels. For example, I have taught communication theory (Washington University ESE 471), transmission and multiplexing (Washington University ESE 571), and signaling and control of communication networks (Washington University ESE 572).

26. I have supervised more than 50 graduate students, 12 of whom received a doctoral degree under my guidance. A number of doctoral theses that I have supervised relate specifically to wireless technology. My students and I have published a number of peer-reviewed articles on resource allocation, scheduling, modulation, mobility management, and multiplexing. Several of these articles received accolades in the field. For example, in 2011, we received a best paper award in 3G WCDMA and 4G LTE related mobility and resource management at the prestigious Mobility 2011 international conference.

27. In addition to my responsibilities as a university faculty member, I have founded two companies. In May 1997, I founded MinMax Technologies, Inc., a fabless semiconductor company that developed switch fabric integrated circuit chips for the Internet. In March 1999, I founded Erlang Technology, Inc., a fabless semiconductor company that focused on the design and development of integrated circuit chips and software for the Internet. One of Erlang's products received a best product of the year award in 2004 from a major trade journal for the electronics industry.

28. Outside my own start-up companies, I have also served in various technology and business advisor roles for other companies and organizations around

the world. I was the main technical author for one of two winning proposals to the Korean government for CDMA wireless service licenses (1996). I was responsible for designing a commercial scale IS-95 CDMA cellular network, which I understand to be one of the earliest such networks deployed in the world. I worked with numerous engineers and scientists around the world to implement this commercial-scale cellular network before IS-95 CDMA was widely accepted. This provided me with extensive insight into various components of cellular technology, which by and large are used in today's 3G and 4G networks. I have also been involved in a semiconductor company that specializes in semiconductor memories, such as flash EEPROMs, as a board member and as a technical advisor (2007-2011).

29. I am a named inventor on ten U.S. patents, many of which are directly related to resource allocation, packet processing, and network designing. I have extensively published technical papers in international journals and at international conferences as well as technical memoranda and reports, and I have given a number of seminars and invited talks. Many of these papers are specifically within the context of the 3GPP standards. I have organized several international conferences and served as an international journal editor.

30. I am a member of, and have been actively involved in, a number of professional organizations. For example, I have served as the Chair of the St. Louis Section of the IEEE, which has more than 3,000 members (2014), and a member of the Eta Kappa Nu Honor Society for electrical engineers. I have also been an Ambassador of the McDonnell International Scholars Academy (2007-2013).

31. In my over 30 years of experience with telecommunications technology, I have acquired significant knowledge about telecommunications systems industry standards and standard setting organizations such as 3GPP.

IV. Technology Background for the Patents-In-Suit

32. In order to aid the discussions that I have presented in this declaration, I have provided below a brief technology background for the Patents-In-Suit.

A. Beamforming

33. In wireless communication, a transmitter transmits radio frequency (RF) signals over the wireless medium. A particular definition varies regarding the term "radio frequency signal," but generally the radio frequency signals relate to the signals utilizing frequencies greater than the audible signals and less than the visible signals. In this way, an RF signal may be in tens of kilohertz (khz = 10^3 cycles per second) to tens of gigahertz (Ghz = 10^9 cycles per second). For example, in the United States, the broadcast AM radio utilizes between about 530 khz and 1600 khz, and the broadcast FM radio utilizes between about 88 megahertz (Mhz = 10^6 cycles per second) and 108 Mhz.

34. When a transmitter transmits a sine wave (or tone) to a receiver at a particular frequency, depending on the distance between the transmitter and the receiver, the amplitude of the received sine wave varies. This can be seen by considering a wave of water propagating on the water surface radially when a rock hits the water. At any given time, the wave creates peaks and troughs on the surface of the water, which can be seen at different locations.

35. In wireless communication, an RF signal propagates as an electromagnetic wave, which travels in a wireless medium at the speed of light. As fast as the speed of light may be, it is still finite and for a different distance away from the transmitter, it takes a different amount of time before the RF signal is received.

36. Consider now two transmitters, each generating a sine wave at the same frequency. A receiver located at certain distances away from the two transmitters

receives two different sine waves from the transmitters and depending on the distance from each transmitter, the receiver observes a different magnitude of the received signal from the individual transmitter.

37. If the two sine waves from the transmitters happen to coincide in phase at the receiver, the combined wave has the magnitude equaling the sum of the two sine wave amplitudes. For example, if the received signal from the first transmitter is $A_1\sin(\omega t)$ and the received signal from the second transmitter is $A_2\sin(\omega t)$, then the combined signal at the receiver becomes $(A_1 + A_2)\sin(\omega t)$. If, on the other hand, the two sine waves happen to coincide in opposite phase, the combined wave has the magnitudes equaling the difference of the two sine wave amplitudes. Following the above example, if the received signal from the first transmitter is $A_1\sin(\omega t)$ and the received signal from the second transmitter is $A_2\sin(\omega t+180^o) = - A_2\sin(\omega t)$, then the combined signal at the receiver becomes $(A_1 - A_2)\sin(\omega t)$. The combination of two sine waves in phase is referred to as a constructive combination and the combination of the two sine waves in opposite phase is referred to as a destructive combination.

38. Again using the example of rocks hitting the water, when two rocks hit the water at two locations at the same time, two waves start propagating radially, and they meet and generate the combined wave patterns on the water surface. Depending on the location on the water surface, the water waves may show a greater peak or trough value (i.e., constructive combination) or show a lesser displacement up or down (i.e., destructive combination).

39. When a transmitter transmits an RF signal, the strength of the received signal depends largely on the distance from the transmitter. This is because the transmitter emits the RF signal radially much like the way a rock generates a wave on the water surface. Consider now that a receiver is located at certain distances away from multiple transmitters, each generating sine waves at the same frequency.

Since the distances to different transmitters are different, the sine waves from the transmitters arrive at the receiver with different time delays. At this same transmitter frequency, the time delays can be translated into the phases of the received signals, which can be used to create a constructive or destructive combination for the receiver.

40. Utilizing the concept illustrated above, when multiple transmitters are located at carefully designed distances apart, it is possible to take advantage of the channel condition and pre-code the transmit signal to generate a combined signal that can be received and decoded with a large amplitude at some locations, while at some other locations, the combined signals may be received with a small to no amplitude, which cannot be decoded.

41. When the transmitters work together to deliver the RF signals to a location focused around the intended receiver, it is like forming a beam of light to shine only at the intended area, thus the term "beamforming." This is the concept of the "beamforming" in wireless communication.

B. Singular Value Decomposition (SVD)

42. To explain the singular value decomposition, I will refer to a widely used undergraduate textbook, Matrix Computations, third edition, by Gene H. Golub and Charles F. Van Loan. ("Golub and Van Loan") (Exhibit F). Golub and Van Loan was published in 1996.

43. Golub and Van Loan states the following theorem on page 70.

Theorem 2.5.2 (Singular Value Decomposition (SVD)) *If A is a real m-by-n matrix, then there exist orthogonal matrices*

$$U = [\, u_1, \ldots, u_m \,] \in R^{mxm} \text{ and } V = [\, v_1, \ldots, v_n \,] \in R^{nxn}$$

such that

$$U^T AV = diag\,(\sigma_1, \ldots, \sigma_p) \in R^{mxn} \quad p = min\,\{m, n\}$$

where $\sigma_1 \geq \sigma_1 \geq \ldots \geq \sigma_p \geq 0$.

44. Theorem 2.5.2 of Golub and Van Loan is closely related to the equation H = UDV* given in the '862 patent at 3:31. To see this, I multiply m-by-m matrix U on the left side of the U^TAV and n-by-n matrix V^T on the right side of U^TAV. Then,

$$U^TAV = diag\ (\sigma_1,\ \ldots,\ \sigma_p)$$

$$UU^TAVV^T = U\ diag\ (\sigma_1,\ \ldots,\ \sigma_p)V^T$$

$$(UU^T)A(VV^T) = U\ diag\ (\sigma_1,\ \ldots,\ \sigma_p)V^T$$

$$I_{mxm}\, A\, I_{nxn} = U\ diag\ (\sigma_1,\ \ldots,\ \sigma_p)V^T$$

$$A = U\ diag\ (\sigma_1,\ \ldots,\ \sigma_p)V^T$$

45. In the above equations, I_{mxm} is an m-by-m identity matrix and I_{nxn} is an n-by-n identity matrix. This is because as stated in Theorem 2.5.2 of Golub and Van Loan, U and V are orthogonal matrices, and the values of U and V may be chosen so that each column of U and V has a unit magnitude.

46. In comparison with the equation H = UDV* given in the '862 patent at 3:31, m-by-n matrix A is a simple substitution of notation for H, and $U^* = U^T$ and $V^* = V^T$ for the real values for U and V. (For real valued matrices, both "*" and "T" represent a transpose of the matrices.[1]) Finally, *diag* $(\sigma_1,\ \ldots,\ \sigma_p)$ equates to the diagonal matrix D.

47. Golub and Van Loan state that "[t]he σ_i are the singular values of A and the vectors u_i and v_i are the *ith left singular vector* and the *ith right singular vector* respective." (Golub and Van Loan at 70.) The concept of singular value is closely related to another concept in the matrix theory called "eigenvalue."

48. Golub and Van Loan explain that "[t]he *eigenvalues* of a matrix $A \in C^{nxn}$ are the n roots of its *characteristic polynomial* $p(z) = det(zI - A)$. The set of

[1] In the '450 patent, "H" is used instead of "*," which is the same complex transpose operation of the matrix.

these roots is called the *spectrum* and is denoted by $\lambda(A)$." (Golub and Van Loan at 310.) Golub and Van Loan further explain that "[i]f $\lambda \in \lambda(A)$, then the nonzero vectors $A \in C^n$ that satisfy $Ax = \lambda x$ are referred to as eigenvectors." (Golub and Van Loan at 310-311.) In comparison, with regard to the singular value σ_i, Golub and Van Loan state that "$Av_i = \sigma_i u_i$ and $A^T u_i = \sigma_i v_i$ where i takes a value between 1 and $min\ \{m, n\}$." (Golub and Van Loan at 71.) Clearly the eigenvalues are related to the singular values and the eigenvectors are related to the singular vectors (both left and right).

49. The eigenvalues and the singular values describe the gain factors for vector amplitude for the eigenvectors and the singular vectors, respectively, where the eigenvalues are for a square matrix and the singular values are for a matrix with a general dimension. That is to say, the singular values are found for m-by-n matrices where m may not be equal to n, whereas the eigenvalues are found for square matrices having an equal number of rows and columns. Whereas the left and right eigenvectors are the same, the left and right singular vectors may be different.

50. Calculating U and V for a given matrix A requires certain algebraic manipulation. As I have shown above, Theorem 2.5.2 of Golub and Van Loan leads to $A = U\ diag\ (\sigma_1, \ldots, \sigma_p)V^T$. From this, to determine U, the following procedure may be followed.

$$AA^T = (U\ diag\ (\sigma_1, \ldots, \sigma_p)V^T)\ (U\ diag\ (\sigma_1, \ldots, \sigma_p)V^T)^T$$
$$AA^T = (U\ diag\ (\sigma_1, \ldots, \sigma_p)V^T)\ (V\ diag\ (\sigma_1, \ldots, \sigma_p)^T\ U^T)$$
$$AA^T = U\ diag\ (\sigma_1, \ldots, \sigma_p)V^T\ V\ diag\ (\sigma_1, \ldots, \sigma_p)^T\ U^T$$
$$AA^T = U\ diag\ (\sigma_1, \ldots, \sigma_p)\ diag\ (\sigma_1, \ldots, \sigma_p)^T\ U^T\ (\text{since } V^T\ V = I_{nxn})$$
$$AA^T = U\ diag\ (\sigma_1^2, \ldots, \sigma_p^2)\ U^T\ (\text{since } diag\ (\sigma_1, \ldots, \sigma_p) = diag\ (\sigma_1, \ldots, \sigma_p)^T)$$
$$AA^TU = U\ diag\ (\sigma_1^2, \ldots, \sigma_p^2)\ U^TU$$

$AA^TU = U\ diag\ (\sigma_1^2, \ldots, \sigma_p^2)$ (since $U^T U = I_{mxm}$)

which leads to $AA^Tu_i = \sigma_i^2 u_i$.

51. Comparing $AA^Tu_i = \sigma_i^2 u_i$ with the condition for the eigenvalues, namely $Ax = \lambda x$, it is clear that each column of U is an eigenvector of AA^T and $\sigma_1^2, \ldots, \sigma_p^2$ ($p = min\ \{m, n\}$) are the eigenvalues of U. As such, m-by-m matrix U can be determined by calculating m eigenvectors of m-by-m matrix AA^T.

52. Next to determine V, the following procedure may be followed.

$A^TA = (U\ diag\ (\sigma_1, \ldots, \sigma_p)V^T)^T (U\ diag\ (\sigma_1, \ldots, \sigma_p)V^T)$

$A^TA = (V\ diag\ (\sigma_1, \ldots, \sigma_p)^T\ U^T)\ (U\ diag\ (\sigma_1, \ldots, \sigma_p)V^T)$

$A^TA = V\ diag\ (\sigma_1, \ldots, \sigma_p)^T\ U^T\ U\ diag\ (\sigma_1, \ldots, \sigma_p)\ V^T$

$A^TA = V\ diag\ (\sigma_1, \ldots, \sigma_p)^T\ diag\ (\sigma_1, \ldots, \sigma_p)\ V^T$ (since $U^T U = I_{mxm}$)

$A^TA = V\ diag\ (\sigma_1^2, \ldots, \sigma_p^2)\ V^T$ (since $diag\ (\sigma_1, \ldots, \sigma_p) = diag\ (\sigma_1, \ldots, \sigma_p)^T$)

$A^TAV = V\ diag\ (\sigma_1^2, \ldots, \sigma_p^2)\ V^TV$

$A^TAV = V\ diag\ (\sigma_1^2, \ldots, \sigma_p^2)$ (since $V^TV = I_{nxn}$)

which leads to $A^TAv_i = \sigma_i^2 v_i$.

53. Comparing $A^TAv_i = \sigma_i^2 v_i$ with the condition for the eigenvalues, namely $Ax = \lambda x$, it is clear that each column of V is an eigenvector of A^TA and $\sigma_1^2, \ldots, \sigma_p^2$ ($p = min\ \{m, n\}$) are the eigenvalues of V. As such, n-by-n matrix V can be determined by calculating n eigenvectors of n-by-n matrix A^TA.

54. To be clear, calculating the eigenvalues and eigenvectors is rudimentary algebra, and is taught as part of any undergraduate engineering curricula. It is a straightforward algebraic exercise, which can be performed by hand for a small value of m and n, or by any one of many widely available computer programs such as Matlab. (See, https://www.mathworks.com/products/matlab-

online.html, for online Matlab, which can be used to calculate eigenvalues and eigenvectors.)

V. Legal Principles for Claim Construction

55. Within this statement, I apply my understanding of certain legal standards to opine on the scope and meaning of certain disputed claim terms. However, I am not a lawyer or an expert in patent law. Following is my understanding of these legal standards.

56. My understanding is that a patent claim should be interpreted based on what it would mean to a POSITA as of the filing date of the patent. Among other information, the claim language and specification are relevant to determining the meaning of the patent claim. Because a claim is interpreted according to its meaning to a POSITA, the knowledge, education, and experience of a POSITA are also relevant to determining the scope and meaning of a patent claim.

57. A primary source for construing a claim term is the plain meaning to a POSITA of the claim term itself. My understanding is that the claims are to be construed from the terms as written. The language of the claims is not to be re-written through interpretation. Other claims in the patent can also be informative, because claim terms are normally used consistently throughout the patent. It is also my understanding that language in a claim should not be construed so as to render claim language superfluous.

58. I understand that claims are read in light of the specification as understood by a POSITA. One should look to the specification and other intrinsic evidence for assistance in understanding a claim term because a patentee may have ascribed a particular meaning to a term. However, unless stated otherwise in the patent document or prosecution history, it is my understanding that limitations from the specification generally should not be read into the claims.

59. I also understand that the prosecution history of a patent provides the record of the examination of a patent application before the U.S. Patent and Trademark Office (PTO). The prosecution history provides evidence of how the patent examiner and the inventor understood the patent application and the claims, and can therefore be instructive on how to interpret the claims. It is my understanding that arguments or amendments made concerning one patent application can be instructive as to the meaning of like terms in another related patent application.

60. My understanding is that there are at least two circumstances where the words in a patent claim may differ from and not be given their plain and ordinary meaning. One circumstance is when the applicants act as their own lexicographer by clearly setting forth a definition of a claim term that may differ from the plain and ordinary meaning it would otherwise possess. Another circumstance is when the applicant includes or provides an intentional disclaimer, or disavowal, of claim scope. My understanding is that an applicant may act as their own lexicographer, or disclaim or disavow claim scope, in either the specification or the prosecution history of the patent. My understanding is also that the applicant may act as a lexicographer, or disclaim or disavow claim scope, by making amendments to the claims during prosecution, or by making assertions to the PTO about the differences between the claimed inventions and the prior art.

61. My understanding is that extrinsic evidence may also be used in understanding the meaning of a claim term. Extrinsic evidence includes dictionaries, treatises, expert testimony, and prior art. But it is my understanding that one should first look to the intrinsic evidence in construing claims.

62. My understanding is that a patent claim element can be expressed in so-called "means-plus-function" format. When expressed in this format, the claim will

recite "means" for performing a specified function. In order to interpret and construe the meaning of a claim element in this format, my understanding is that the first step is to identify the recited function of the claim element. The second step is to refer to the specification, identifying any structure that the specification discloses and links to performing the claimed function. This structure should be sufficient to perform the claimed function.

63. My understanding is that a claim term is to be construed as a means-plus-function term even if it does not use the word "means," if the term (a) fails to recite sufficiently definite structure or (b) recites function without reciting sufficient structure for performing that function. I further understand that generic terms such as "mechanism," "element," "device," "module," and other nonce words are tantamount to using the word "means" because they typically do not connote sufficiently definite structure.

64. My understanding is that if the specification fails to disclose adequate corresponding structure to perform the claimed function, the claim is indefinite. Where the claimed function for a means-plus-function element can only be performed by specialized software executed by a general purpose computer, the specification must disclose an algorithm for performing the claimed function. I understand that if the specification fails to disclose an algorithm, the claim is indefinite for failure to disclose sufficient structure.

65. My understanding is that a patent claim is indefinite if the claim fails to inform, with reasonable certainty, those skilled in the art about the scope of the invention, when the claim is read in light of the specification delineating the patent and the prosecution history.

VI. The ’156 Patent

A. Summary

66. U.S. Patent No. 6,941,156 to Philip D. Mooney (“the ’156 Patent”), is entitled “Automatic Handoff for Wireless Piconet Multimode Cell Phone” and was issued on September 6, 2005.

67. The ’156 Patent is directed to handoffs “between two different modes of a multimode cell phone.” ’156 Patent, Abstract. For example, the ’156 Patent states that the “invention provides a technique for transferring an active telephone call from cordless telephone mode to cell phone mode (and vice versa).” *Id*. at 3:26–28.

68. “For explanation purposes, FIG. 1 depicts an established telephone call between the multimode cell phone 100 and a far end telephone 150 (which in the example is a landline telephone accessed through a cellular network).” *Id*. at 4:12–15. The specification explains that:

> Once the multimode cell phone 100 extends beyond its acceptable range, the telephone call would ordinarily be dropped, perhaps involuntarily. However, in accordance with the principles of the present invention, the telephone call between the multimode cell phone 100 and the far end telephone 150 is automatically re-established using the cellular network 120. By automatically changing the mode of the multimode cell phone 100 (preferably subsequent to a prompt to the user for permission to transfer), the conversation or other communication between the parties is transferred to the newly established cell phone call.

Id. at 4:17–27.

69. “FIG. 2 shows an exemplary process for handing over a telephone call from the cordless mode of a multimode cell phone to a cellular mode of the multimode cell phone, in accordance with the principles of the present invention.” *Id*. at 4:50–53.

FIG. 1

CORDLESS TO CELL PHONE HAND OVER

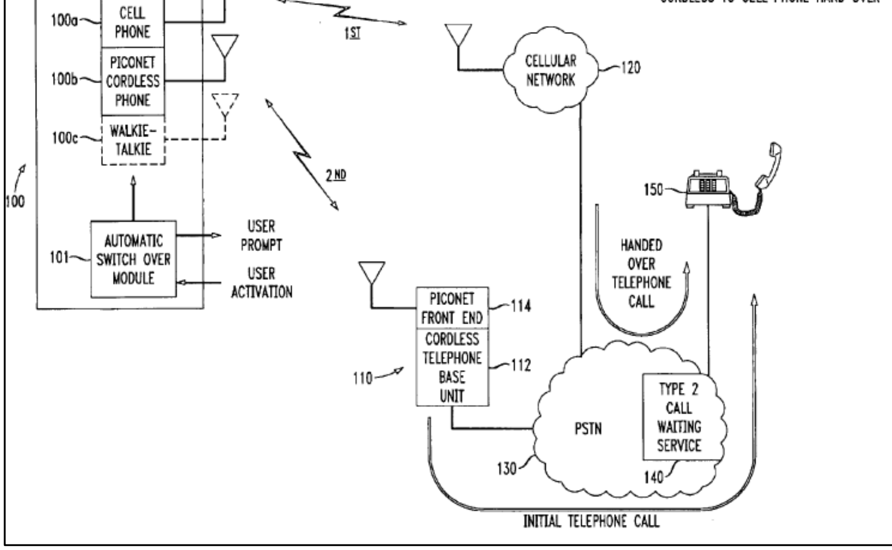
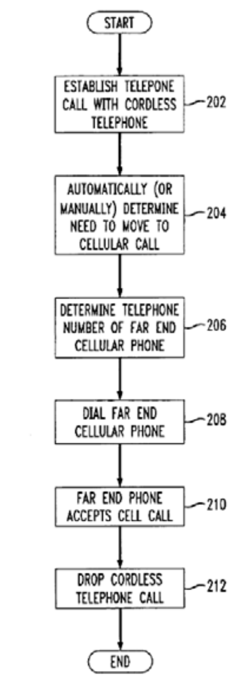


FIG. 2

CORDLESS TO CELL PHONE HAND OVER



B. Person of Ordinary Skill in the Art ("POSITA")

70. In order to determine the characteristics of a person of ordinary skill in the art of the '156 Patent, I have used the dates between August 1, 2000 and June 26, 2001 as the relevant time frame. My understanding is the application for the '156 Patent was filed on June 26, 2001, but that BNR may allege the claimed invention may be entitled to a priority date as early as August 1, 2000.

71. For purposes of this statement, any reference to the filing date of the '156 Patent is intended to refer to the earliest priority date to which the '156 Patent is entitled between August 1, 2000 and June 26, 2001.

72. In determining the characteristics of a person of ordinary skill for the '156 Patent, I have considered the state of the art of wireless mobile communication systems at that time, the types of problems encountered with mobile telephony, including call processing and call handoffs, and the solutions that then existed for mobile equipment such as those specified in standards for wireless communications (e.g., 3GPP/ETSI, etc.). I have also considered the then-existing technology for wireless communication systems, such as cellular radio systems, public switched telephone networks (PSTN), cordless telephones, and wireless local area network systems (e.g., IEEE 802.11 Wi-Fi systems), including the sophistication of the technology involved. I have also considered the education and experience of those working in the field at that time. I have also considered my personal knowledge and experience with the field at that time, including those I worked and interacted with regarding wireless mobile communication systems. I have also considered the knowledge, education, and experience of those in academia and industry at that time that were working, innovating, or performing research in the field of wireless mobile communication systems, and in particular, techniques to address handoff and inter-system compatibility problems.

73. It is my opinion that a POSITA for the ’156 Patent at the time of this filing date would have had a Bachelor’s degree in Electrical Engineering, Computer Engineering, Computer Science, or a related field, and at least 2 years of experience in the field of wireless communication, or a person with equivalent education, work, or experience in this field.

C. Construction of the Disputed Terms in the ’156 Patent

74. I have been asked to opine on the meaning of five claim terms in the ’156 Patent: (a) “simultaneous communication paths from said multimode cell phone,” (b) “cell phone functionality,” (c) “RF communication functionality,” (d) “a module to establish simultaneous communication paths from said multimode cell phone using both said cell phone functionality and said RF communication functionality,” and (e) “an automatic switch over module, in communication with both said cell phone functionality and said RF communication functionality, operable to switch a communication path established on one of said cell phone functionality and said RF communication functionality, with another communication path later established on the other of said cell phone functionality and said RF communication functionality.”

75. For my analysis, I have reviewed and considered the ’156 Patent’s specification, claims, prosecution history, and the Schellinger prior art reference (U.S. Pat. No. 5,842,122) cited in the prosecution history. Based on this intrinsic evidence, I have interpreted these claim terms as they would have been understood by a POSITA as of the filing date of the ’156 Patent as explained below. I understand that BNR has not identified extrinsic support to establish the meaning of these terms, aside from the possible (but not yet disclosed) testimony of its expert.

a. *“simultaneous communication paths from said multimode cell phone”*

’156 Patent Claim Term	BNR’s Proposed Construction	Defendants’ Proposed Construction
“simultaneous communication paths from said multimode cell phone”	Plain and ordinary meaning. In the alternative, to the extent the Court determines that a specific construction is warranted, BNR proposes: “two or more active links at the same time from said multimode cellphone”	“at least two established distinct and different communication links from said multimode cell phone to a far-end communication device, at the same time”

Joint Claim Construction Worksheet, Appendix A at 34–35.

76. The term “simultaneous communication paths from said multimode cell phone” is used in claim 1.

77. It is my opinion that, at the time of the filing of the ’156 Patent, a POSITA would understand this term to mean “at least two established distinct and different communication links from said multimode cell phone to a far-end communication device, at the same time,” as Defendants propose. My opinion is supported by the disclosures in the ’156 Patent and the prosecution history as I explain in the following paragraphs.

78. The Abstract of the ’156 Patent states that the invention is directed to “transferring a communication link between two different modes of a multimode cell phone.” ’156 Patent, Abstract. The specification discloses a multimode cell phone embodiment having three modes: “cell phone/cordless telephone/walkie-talkie.” *Id.* at 8–10.

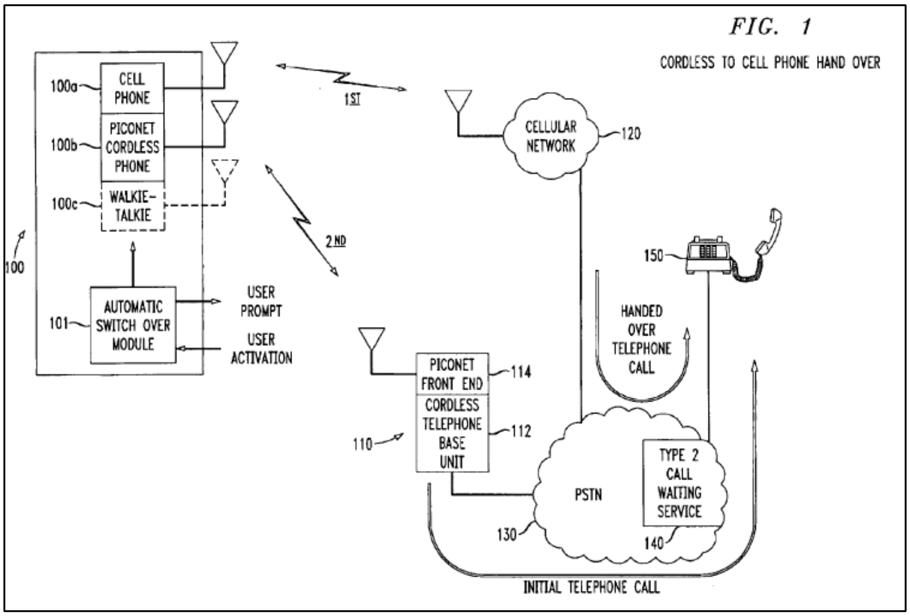
79. The patent explains that a handover between modes is made possible while the multimode cell phone is in a call using one mode by the multimode cell

phone's simultaneous operation in another mode to establish a secondary "communication link therebetween" the two parties:

> Preferably, more than one mode of the multimode cell phone 100 may operate simultaneously, allowing the establishment of a secondary communication path in the background, allowing easy and quick switch over as desired or required. For instance, while operating in a cell phone mode, the automatic switch over module 101 of the multimode cell phone 100 may detect walkie-talkie communication activity from the far party's multimode cell phone 100, and **establish a communication link therebetween** even while the two parties remain in a cell phone conversation.

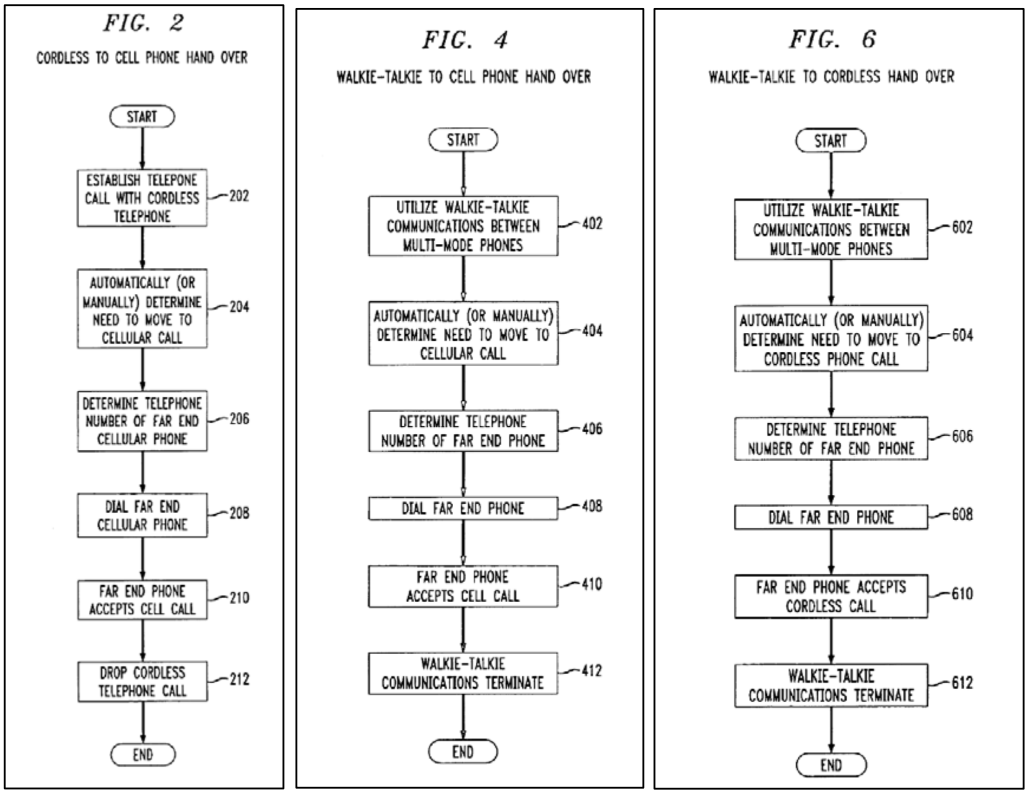
Id. at 3:64–4:6. The patent specification explains that "[b]y automatically changing the mode of the multimode cell phone 100 (preferably subsequent to a prompt to the user for permission to transfer), the conversation or other communication between the parties is transferred to the newly established cell phone call." *Id*. at 4:23–27.

80. Defendants' proposed construction is supported by Figure 1, which uses arrows to show that the "initial telephone call" and the "handed over telephone call" are on "distinct and different communication links" to a "far-end communication device" (telephone 150).



Id. at Fig. 1.

81. The ’156 Patent discloses three exemplary processes for handing over a telephone call between modes. Figure 2 shows a process for handing over a telephone call from the cordless mode to a cellular mode. Figure 4 shows a process for handing over a walkie-talkie conversation to a cellular telephone call. Figure 6 shows a process for handing over a walkie-talkie conversation to a cordless telephone call.



Id. at Figs. 2, 4, 6.

82. During an already established call that is to be handed over, each process includes a step to "dial" the "far end" phone. *Id*. at Fig 2 (step 208), Fig. 4 (step 408), Fig. 6 (step 608). Then, in the next step, the "far end phone accepts" the call. *Id*. at Fig 2 (step 210), Fig. 4 (step 410), Fig. 6 (step 610).

83. Defendants' proposed construction is consistent with these three handover processes, which each illustrate establishing two "distinct and different communication links from said multimode cell phone to a far-end communication device, at the same time."

84. The '156 Patent specification explains that the initial communication path is maintained for a period of time after the handover:

> In step 212, the old communication path (in this case the cordless telephone call) is dropped, perhaps after a desirable delay (e.g., after 5 seconds).

Id. at 5:4–6. According to the specification, maintaining simultaneous communication paths to the far-end device for a period of time allows the users to switch back to the initial call in the event that the switchover does not succeed:

> In the unlikely event that the switchover does not succeed, the switchover is preferably delayed (e.g., for 10 seconds or more) to allow the users to switch back to the initial telephone call or communication path.

Id. at 6:40–44. This is sometimes referred to as a "make-before-break" handover. The '156 Patent's disclosure that the simultaneous communications paths are maintained for a time even after handover further supports Defendants' construction that there are two links "to a far-end communication device, at the same time."

85. Defendants' construction is also supported by the specification's disclosure that Call Waiting is used "to switch the far end telephone from one line to the other."

> In particular, in accordance with the principles of the present invention, CallerID Type2 and Call Waiting are used to switch the far end telephone from one line to the other with minimal (or even unnoticeable) disruption to the participants or content of the telephone connection.

Id. at 3:29–33. A POSITA would understand that the specification is explaining that Call Waiting is used by the far end telephone device to switch between two "established distinct and different communication links from said multimode cell phone to a far-end communication device."

86. BNR's construction is incorrect for several reasons. First, BNR's proposal that simultaneous communication paths are "active links" fails to account

for the '156 Patent's disclosure that the claimed invention is directed to handovers between different modes of a multimode cell phone. Defendants' proposed construction recognizes this by construing the term to mean "distinct and different communication links." Moreover, BNR's proposal is confusing, because BNR does not explain the meaning of the term "active." To a POSITA, an active link could mean a link maintaining transmission and reception of data or an active link also could mean a link simply maintaining the connected state without transmitting and receiving data. A POSITA would have known that a multimode cell phone could be connected to another device without exchanging data for a certain period of time before it is timed out.

87. Second, BNR's proposed construction provides no basis to ascertain both end points of the "simultaneous communication path." A POSITA would understand that a communication path must have two end-points, one at the multimode cell phone and another at a far-end communication device. As explained above, the specification discloses that the communication path is from "said multimode cell phone to a far-end communication device," consistent with Defendants' proposed construction.

88. Third, BNR's proposed construction is in conflict with arguments and amendments made by the applicant for the '156 Patent during prosecution in response to an Office Action rejecting all 19 original claims as anticipated by U.S. Patent No. 5,842,122 to Schellinger, et al. ("Schellinger"). U.S. Patent Appl. No. 09/888,493, Dec. 8, 2004 Office Action (BNR-SDCA00000059–64). Schellinger discloses "automatic handoff operation" when portable cellular cordless (PCC) radiotelephone 101 "moves out of range of the cordless telephone system and is in the coverage area of the cellular telephone system" (Schellinger, 6:61–7:6):

> In accordance with the preferred embodiment of the present invention, a call in process between the PCC 101 operating in a cellular telephone system 103 and a calling party is handed off from the cellular telephone system 103 to the cordless telephone system by producing a three way call through the cellular telephone system 103, at block 716, between the PCC 101, the other party and the landline phone number of the cordless base station 115.
>
> In FIG. 6-2 the cordless base station 115 receives the handoff from cellular to cordless request at block 617 and answers the landline leg of the three way call at block 619 to open communication between the other party and the cordless base station 115. The PCC 101 is now in a cordless phone call with the calling party at block 621. In FIG. 7A the PCC 101 operating in the cellular telephone system 103 ends the cellular leg of the three way call at block 718 to terminate cellular system communication between the PCC 101 and the other party. Thus, a call in process is handed off from the cellular telephone system 103 to the cordless telephone system when the PCC 101 relocates from the cellular telephone system 103 to the cordless telephone system.

Schellinger, 7:50–8:3.

89. In response to the Patent Office's rejection, the patent applicant amended the claims. For example, claim 1 was amended to further include the limitation "a module to establish simultaneous communication paths from said multimode cell phone using both said cell phone functionality and said RF communication functionality." U.S. Patent Appl. No. 09/888,493, Jan. 6, 2005 Response to Office Action (BNR-SDCA00000073).

90. In addition, the applicant distinguished the amended claims over the Schellinger reference by arguing that Schellinger disclosed a radiotelephone that switched between modes, but that radiotelephone did not operate in "both [modes] simultaneously." The applicant also argued that the handoff was produced using a "three way call through the cellular telephone system." A POSITA would

understand that the three way call disclosed by Schellinger reflected two links from the radiotelephone to the telephone network—one link from the radiotelephone that terminated at the cellular telephone system and another link from the radiotelephone's cordless base station that terminated at a central office and/or cellular telephone system:

> The cited art of Schellinger instructs a central office (or cellular telephone system) to set up a three way call, and the cell phone answers and stays with the third party call when received.
>
> In particular, Schellinger discloses a dual mode cellular cordless portable radiotelephone that is capable of ONE mode of communication, or the OTHER, BUT NOT BOTH SIMULTANEOUSLY.
>
> In particular, Schellinger discloses automatic routing of an incoming call without inconveniencing the user. (Schellinger, col. 5, lines 10-13). A portable cellular cordless (PCC) device decides whether to remain in a cellular telephone system, or to change to a cordless telephone system. (Schellinger, col. 5, lines 29-39).
>
> However, according to Schellinger, **automatic forwarding** systems **of a central office** are implemented to allow handoff of a call. See, e.g., col. 6, lines 12-15; and col. 6, line 24 (remote call forwarding performed). As explained by Schellinger at col. 7, lines 50-62, a call in process is handed off by producing a THREE WAY CALL through the **cellular telephone system** (i.e., NOT through the cell phone itself). To finally implement the handoff, the cell phone switches to a landline leg of a **three way call** (set up by a central office and/or cellular telephone system), and the initial call is dropped.

U.S. Patent Appl. No. 09/888,493, Jan. 6, 2005 Response to Office Action (BNR-SDCA00000078–79). The examiner allowed the amended claims in response to the applicant's arguments. U.S. Patent Appl. No. 09/888,493, Apr. 26, 2005 Notice of Allowance (BNR-SDCA00000084).

91. BNR's proposed construction of "two or more active links at the same time from said multimode cellphone" would encompass communication paths that terminate at the telephone network, as Schellinger disclosed, and thus cannot be correct because that would encompass handovers produced by "a three way call through the cellular telephone system," which the applicants explicitly distinguished from the '156 Patent's claims during prosecution. Defendants' construction makes clear that the handover cannot be accomplished by a three way call through the telephone system (i.e., two links to the telephone system), but instead is accomplished by two links to the far-end communication device.

92. Accordingly, it is my opinion that a POSITA would understand the term "simultaneous communication paths from said multimode cell phone" to mean "at least two established distinct and different communication links from said multimode cell phone to a far-end communication device, at the same time."

b. *"cell phone functionality"*

'156 Patent Claim Term	BNR's Proposed Construction	Defendants' Proposed Construction
"cell phone functionality"	Not a 112 ¶ 6 claim element – "cell phone functionality" is not a nonce word. Instead, cell phone functionality is itself sufficient structure. A POSA would know this is a cellular RF communication functionality well known in the art.	This is a 112 ¶ 6 claim element. Function: "cell phone" Structure: Indefinite for lack of corresponding structure in the patent specification. Huawei and Coolpad Defendants state alternatively, to the extent that the Court requires an identification of structure, the

’156 Patent Claim Term	BNR’s Proposed Construction	Defendants’ Proposed Construction
		cell phone 100a and corresponding antenna depicted in Fig. 1 are insufficient structure to perform the claimed function.

Joint Claim Construction Worksheet, Appendix A at 35–37.

93. The term “cell phone functionality” is used in claim 1.

94. It is my opinion that, at the time of the filing of the ’156 Patent, a POSITA would understand this term to be a means-plus-function term that is indefinite for lack of corresponding structure to perform the recited function. My opinion is supported by the disclosures in the ’156 Patent as I explain in the following paragraphs.

95. In my opinion, a POSITA would understand that the claim term “cell phone functionality” is used in the claim to describe a function to be performed. The term “functionality” does not identify structure. Nor does the term “cell phone functionality” identify structure. Instead, the term explicitly recites functionality.

96. Furthermore, a POSITA would understand that structure to implement a “cell phone,” in the context of the claimed “multimode cell phone,” includes a general purpose computer (e.g., microprocessor). But, a general purpose computer is not sufficient structure to perform the claimed function. An off-the-shelf general purpose computer is not capable of performing “cell phone functionality” without special programming.

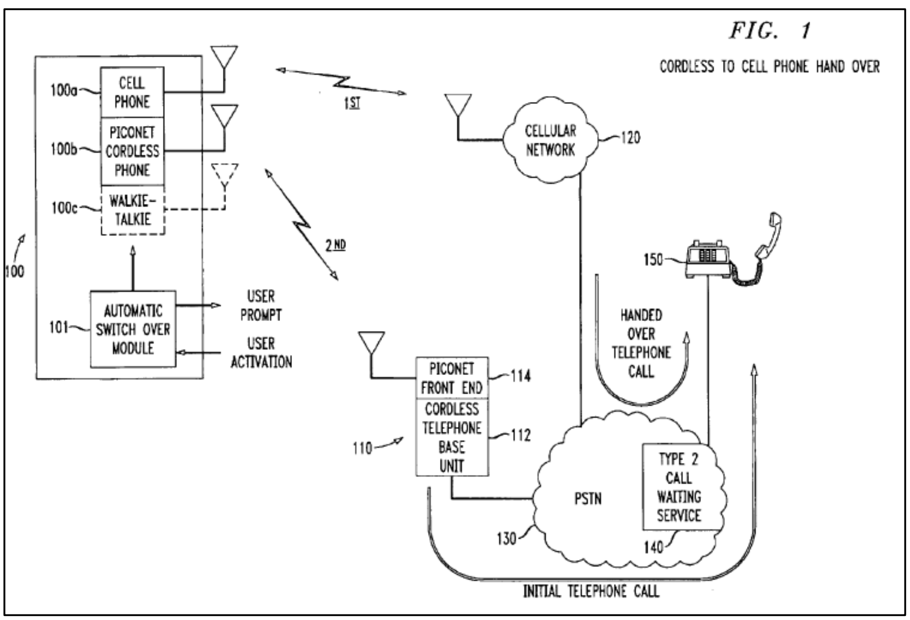
97. As such, I understand that the term “cell phone functionality” must be construed as a means-plus-function term. A POSITA would understand this means-plus-function term to recite a “cell phone” function.

98. The '156 Patent is directed to a "wireless piconet multimode **cell phone**." '156 Patent, Title. The specification describes this device as a "3-in-1 **cell phone**":

> One of the new and useful ideas coming out of BLUETOOTH technology is the **3-in-1 cell phone**, where **a cell phone** has advanced and additional capabilities to operate as a cordless telephone when near a matching cordless telephone base station, or to work as a walkie-talkie when near another similarly capable handset. This provides **a cell phone** that has advantages over competitors' cell phones which are not similarly capable, **including the ability and convenience of storing all phone book data, calling history and user preferences**.

Id. at 1:13–22 (bold emphasis added).

99. Figure 1 depicts a "multimode cell phone 100 [that] includes multiple functional modes." *Id*. at 3:52–55.



Id. at Fig. 1.

100. A POSITA would understand that multimode cell phone 100 described by the ’156 Patent must include radio communication equipment (e.g., antenna, amplifier, transmitter, receiver, etc.) operating in conjunction with a general purpose computer (e.g., microprocessor) that is specially programmed to perform wireless communications, typically in compliance with telecommunication industry standards (e.g., 3GPP/ETSI, etc.). According to the specification, the multimode cell phone further includes “the ability and convenience of storing all phone book data, calling history and user preferences” (*id*. at 1:13–22), which a POSITA would also understand to be implemented by a general purpose computer (e.g., microprocessor) that is specially programmed to perform such functionality. The specification further supports this understanding by stating that multimode cell phone 100 operates under the control of a “processor.”[2] *Id*. at 7:9–13, 7:53–57.

101. I disagree with BNR’s statement that “[a] POSA would know this is a cellular RF communication functionality well known in the art.” The ’156 Patent, including the language of claim 1, makes clear that the claimed “multimode **cell phone**” cannot be limited to “cellular RF communication functionality” because it includes functionality to operate as a cordless telephone or walkie-talkie, and because it includes functionality to store phone book data, calling history and user preferences. *Id*. at 1:13–22 (bold emphasis added). BNR’s proposed construction

[2] The ’862 Patent further supports this understanding by disclosing a “wireless communication device,” such as a “cellular telephone” (’862 Patent, 7:21–27, Fig. 3), that includes a “baseband processing module” which executes “operational instructions” (*id.* at 7:51—8:1). The ’862 Patent discloses that the “baseband processing module 100 may be implemented using one or more processing devices,” such as a “microprocessor, micro-controller, digital signal processor, microcomputer, central processing unit, field programmable gate array, programmable logic device, state machine, logic circuitry, analog circuitry, digital circuitry, and/or any device that manipulates signals (analog and/or digital) based on operational instructions.” *Id*. at 8:1–20.

also fails to recognize that a POSITA would understand that the claimed multimode cell phone includes a general purpose computer (e.g., microprocessor) programmed to perform wireless communications.

102. To disclose sufficient structure for a general purpose computer, I understand that the specification must disclose the algorithm for performing the claimed functions. No algorithm is disclosed by the '156 Patent to explain how the "cell phone" function is to be performed by a general purpose computer. Nor does BNR's proposed construction identify such an algorithm. Accordingly, it is my opinion that a POSITA would understand that the "cell phone functionality" term is indefinite for lack of structure to perform the "cell phone" function.

c. *"RF communication functionality"*

'156 Patent Claim Term	BNR's Proposed Construction	Defendants' Proposed Construction
"RF communication functionality"	Not a 112 ¶ 6 claim element – "RF communication functionality" is not a nonce word. Instead, RF communication functionality is itself sufficient structure. A POSA would know this is a structure for RF communications through a genus of RF communication types well known in the art.	This is a 112 ¶ 6 claim element. Function: "RF communication" Structure: Indefinite for lack of corresponding structure in the patent specification. Huawei and Coolpad Defendants state alternatively, to the extent that the Court requires an identification of structure, any of the cordless phone 100b with its corresponding

’156 Patent Claim Term	BNR’s Proposed Construction	Defendants’ Proposed Construction
		antenna and the walkie-talkie 100c with its corresponding antenna, are insufficient structure to perform the claimed function.

Joint Claim Construction Worksheet, Appendix A at 38–40.

103. The term “RF communication functionality” is used in claim 1.

104. It is my opinion that, at the time of the filing of the ’156 Patent, a POSITA would understand this term to be a means-plus-function term that is indefinite for lack of corresponding structure to perform the recited function. My opinion is supported by the disclosures in the ’156 Patent as I explain in the following paragraphs.

105. In my opinion, a POSITA would understand that the claim term “RF communication functionality” is used in the claim to describe a function to be performed. The term “functionality” does not identify structure. Nor does the term “RF communication functionality” identify structure. Instead, the term explicitly recites functionality.

106. Furthermore, a POSITA would understand that structure to implement “RF communication functionality,” as used in the context of the claimed “multimode cell phone,” includes a general purpose computer (e.g., microprocessor). But, a general purpose computer is not sufficient structure to perform the claimed function. An off-the-shelf general purpose computer is not capable of performing “RF communication functionality” without special programming.

107. As such, I understand that the term "RF communication functionality" must be construed as a means-plus-function term. A POSITA would understand this means-plus-function term to recite an "RF communication" function.

108. As explained above, a POSITA would understand that "RF communication functionality" performed by multimode cell phone 100 described by the '156 Patent would include a general purpose computer (e.g., microprocessor) that must be specially programmed to perform RF communications.

109. I disagree with BNR's statement that "[a] POSA would know this is a structure for RF communications through a genus of RF communication types well known in the art." BNR's proposed construction fails to recognize that a POSITA would understand that the claimed multimode cell phone includes a general purpose computer (e.g., microprocessor) programmed to perform wireless communications.

110. No algorithm is disclosed by the '156 Patent to explain how the "RF communication" function is to be performed by a general purpose computer. Nor does BNR's proposed construction identify such an algorithm. Accordingly, it is my opinion that a POSITA would understand that the "RF communication functionality" term is indefinite for lack of structure to perform the "RF communication" function.

d. *"a module to establish simultaneous communication paths from said multimode cell phone using both said cell phone functionality and said RF communication functionality"*

'156 Patent Claim Term	BNR's Proposed Construction	Defendants' Proposed Construction
"a module to establish simultaneous	Not a 112 ¶ 6 claim element – "module" is not a nonce word here.	This is a 112 ¶ 6 claim element.

’156 Patent Claim Term	BNR’s Proposed Construction	Defendants’ Proposed Construction
communication paths from said multimode cell phone using both said cell phone functionality and said RF communication functionality”	Instead, the “module to establish simultaneous communication paths from said multimode cell phone using both said cell phone functionality and said RF communication functionality” is itself sufficient structure. A POSA would know this is a structure for RF communications through a genus of RF communication types well known in the art. In the alternative, to the extent the Court determines that this claim is governed by 112 ¶ 6, BNR proposes the following Function and Structure, and disagrees that the term is indefinite for lack of corresponding structure: <u>Function</u>: establish simultaneous communication paths from said multimode cell phone using both said cell phone functionality and said RF communication functionality	 <u>Function</u>: “establish simultaneous communication paths from said multimode cell phone using both said cell phone functionality and said RF communication functionality”

’156 Patent Claim Term	BNR’s Proposed Construction	Defendants’ Proposed Construction
	Structure: Corresponding structure for the alleged function exists in at least the following portions of the patent specification, or their equivalents: Figs. 1, 3, Col. 3:48–4:49; 4:54–5:62; 6:3–55; 6:60–8:5	Kyocera & ZTE propose: Structure: Indefinite for lack of corresponding structure in the patent specification. Huawei & Coolpad propose: Structure: Fig. 1 (element 101); Fig. 2 steps 202-208; Fig. 4 steps 402-408; 4:50-67; 7:1-16.

Joint Claim Construction Worksheet, Appendix A at 38–40.

111. The term “a module to establish simultaneous communication paths from said multimode cell phone using both said cell phone functionality and said RF communication functionality” is used in claim 1.

112. It is my opinion that, at the time of the filing of the ’156 Patent, a POSITA would understand this term to be a means-plus-function term that is indefinite for lack of corresponding structure to perform the recited function. My opinion is supported by the disclosures in the ’156 Patent as I explain in the following paragraphs.

113. In my opinion, a POSITA would understand that the term “module” is used in the claim as a nonce word. The term “module” is not structure nor does it recite sufficient structure to “establish simultaneous communication paths . . .”

114. As such, I understand that the term “a module to establish simultaneous communication paths from said multimode cell phone using both said cell phone functionality and said RF communication functionality” must be construed as a

means-plus-function term. A POSITA would understand this means-plus-function term to recite the function "establish simultaneous communication paths from said multimode cell phone using both said cell phone functionality and said RF communication functionality." A POSITA would understand that this claimed function is a two-part function. In the first part, the function requires establishing a first communication path from said multimode cell phone on one of said cell phone functionality and said RF communication functionality. In the second part, the function requires establishing a second simultaneous communication path from said multimode cell phone using the other of said functionality and said RF communication functionality.

115. As explained above, a POSITA would understand that the structure to perform the claimed function includes a general purpose computer (e.g., microprocessor) programmed to perform the "establish simultaneous communication paths . . ." function.[3]

116. I disagree with BNR's statement that "[a] POSA would know this is a structure for RF communications through a genus of RF communication types well known in the art." BNR's proposed construction fails to recognize that a POSITA

[3] As explained above, it is my opinion that a POSITA would understand the term "simultaneous communication paths from said multimode cell phone" to mean "at least two established distinct and different communication links from said multimode cell phone to a far-end communication device, at the same time." However, even under BNR's proposed construction that the term "simultaneous communication paths from said multimode cell phone" means "two or more active links at the same time from said multimode cellphone," a POSITA would understand that the structure to implement the claimed "module" must include a general purpose computer (e.g., microprocessor) programmed to perform the "establish simultaneous communication paths . . ." function. Thus, my opinion as to the construction of the claimed "module" does not change under either construction of the "simultaneous communication paths . . ." function.

would understand that the claimed multimode cell phone includes a general purpose computer (e.g., microprocessor) programmed to perform wireless communications.

117. To disclose sufficient structure for a general purpose computer, I understand that the specification must disclose the algorithm for performing the claimed functions. No algorithm is disclosed by the '156 Patent to explain how the "establish simultaneous communication paths . . ." function is to be performed by a general purpose computer. Although a POSITA might be able to create various algorithms to program a general purpose computer to implement the claimed "establish simultaneous communication paths . . . " function, the specification fails to disclose an algorithm for doing so.

118. BNR states that structure is found in the specification at "Figs. 1, 3, Col. 3:48–4:49; 4:54–5:62; 6:3–55; 6:60–8:5," but provides no further details. It is not apparent from these citations what BNR is identifying as structure. Based on my review, no algorithm for performing the "establish simultaneous communication paths . . ." function is disclosed by the information BNR cited. For example, to the extent that BNR contends "step 202" ('156 Patent, 4:54–56) is structure for performing the claimed function, it is my opinion that "step 202" does not identify an algorithm to a POSITA. "Step 202" merely restates the first part of the claimed function, which requires establishing a first communication path: "a cordless telephone call is established using a cordless telephone mode." In other words, "step 202" restates the first part of the claimed function, not the algorithm for performing the function.

119. As another example, to the extent that BNR contends "step 204" (*id*. at 4:57–58) is structure for performing the claimed function, it is my opinion that "step 204" does not identify an algorithm to a POSITA. "Step 204" describes a result: "the need (or desire) to change communication modes to a cellular mode is

determined." "Step 204" fails to disclose how this "need (or desire)" is determined. In other words, "step 204" is directed to determining whether there is a need or desire to change the communication mode, but not "how" that determination is made or "how" to establish a communication path from said multimode cell phone. Thus it fails to disclose to a POSITA an algorithm for performing the claimed function.

120. As another example, to the extent that BNR contends "step 206" (*id*. at 4:59–63) is structure for performing the claimed function, it is my opinion that "step 206" does not identify an algorithm to a POSITA. "Step 206" recites that a telephone number is used: "the telephone number of the far end telephone 150 (or another suitable phone accessible to the far end party) is determined." But, "step 206" does not disclose how to establish a communication path from said multimode cell phone, and thus, fails to disclose to a POSITA an algorithm for performing the claimed function. "Step 206" also states that the number may be determined "using a call related information service provided by the PSTN," but this refers to functionality performed by the public switched telephone network (PSTN), not to functionality that is performed by the claimed multimode cell phone. Thus it fails to disclose to a POSITA an algorithm for performing the claimed function.

121. As another example, to the extent that BNR contends "step 208" (*id*. at 4:64–67) is structure for performing the claimed function, it is my opinion that "step 208" does not identify an algorithm to a POSITA. "Step 208" recites that a number is dialed and is passed through: "the determined telephone number of the far end telephone 150 is dialed, and passes through to the far end telephone 150 using, e.g., a Call Waiting type service 140." But, "step 208" does not disclose how to establish a communication path from said multimode cell phone, and thus, fails to disclose to a POSITA an algorithm for performing the claimed function. "Step 208" also refers to functionality that "passes through" the telephone number and that may use "a Call

Waiting type service," but this refers to functionality performed in the public switched telephone network (PSTN), not to functionality that is performed by the claimed multimode cell phone. There is no disclosure to a POSITA of an algorithm on the claimed multimode cell phone for performing the claimed function.

122. Accordingly, it is my opinion that a POSITA would understand that the "a module to establish simultaneous communication paths from said multimode cell phone using both said cell phone functionality and said RF communication functionality" term is indefinite for lack of structure to perform the "establish simultaneous communication paths . . ." function.

e. *"an automatic switch over module, in communication with both said cell phone functionality and said RF communication functionality, operable to switch a communication path established on one of said cell phone functionality and said RF communication functionality, with another communication path later established on the other of said cell phone functionality and said RF communication functionality"*

'156 Patent Claim Term	**BNR's Proposed Construction**	**Defendants' Proposed Construction**
"an automatic switch over module, in communication with both said cell phone functionality and said RF communication functionality,	Not a 112 ¶ 6 claim element – "module" is not a nonce word here. Instead, the "an automatic switch over module, in communication with both said cell phone functionality and said RF communication	This is a 112 ¶ 6 claim element.

’156 Patent Claim Term	BNR’s Proposed Construction	Defendants’ Proposed Construction
operable to switch a communication path established on one of said cell phone functionality and said RF communication functionality, with another communication path later established on the other of said cell phone functionality and said RF communication functionality”	functionality, operable to switch a communication path established on one of said cell phone functionality and said RF communication functionality, with another communication path later established on the other of said cell phone functionality and said RF communication functionality” is itself sufficient structure. A POSA would know this is a structure for RF communications through a genus of RF communication types well known in the art. In the alternative, to the extent the Court determines that this claim is governed by 112 ¶ 6, BNR proposes the following Function and Structure, and disagrees that the term is indefinite for lack of corresponding structure: <u>Function:</u> in communication with both said cell phone	Kyocera & ZTE propose: <u>Function</u>: “in communication with both said cell phone functionality and said RF communication functionality, operable to switch a communication path established on one of said cell phone functionality and said RF communication functionality, with another communication path later established on the other of said cell phone functionality and said RF communication functionality”

'156 Patent Claim Term	BNR's Proposed Construction	Defendants' Proposed Construction
	functionality and said RF communication functionality, operable to switch a communication path established on one of said cell phone functionality and said RF communication functionality, with another communication path later established on the other of said cell phone functionality and said RF communication functionality Structure: Corresponding structure for the alleged function exists in at least the following portions of the patent specification, or their equivalents: Figs. 1, 3, Col. 3:48–4:49; 4:54–5:62; 6:3–55; 6:60–8:5	Structure: Indefinite for lack of corresponding structure in the patent specification. Huawei & Coolpad propose: Function: "automatic switch over of a communication path established on one of said cell phone functionality and said RF communication functionality, with another communication path later established on the other of said cell phone functionality and said RF communication functionality" Structure: Fig. 1 (element 101); Fig. 2 steps 210-212; Fig. 4 steps 410-412; 5:1-7; 7:17-26, claim 1 ("an automatic switch over module, in communication with both said cell phone functionality and said RF communication functionality").

Joint Claim Construction Worksheet, Appendix A at 38–40.

123. The term "an automatic switch over module, in communication with both said cell phone functionality and said RF communication functionality,

operable to switch a communication path established on one of said cell phone functionality and said RF communication functionality, with another communication path later established on the other of said cell phone functionality and said RF communication functionality" is used in claim 1.

124. It is my opinion that, at the time of the filing of the '156 Patent, a POSITA would understand this term to be a means-plus-function term that is indefinite for lack of corresponding structure to perform the recited function. My opinion is supported by the disclosures in the '156 Patent as I explain in the following paragraphs.

125. In my opinion, a POSITA would understand that the term "module" is used in the context of "an automatic switch over module" as a nonce word. The term "module" is not structure. Neither the term "automatic switch over module" nor the language of the claim itself recite sufficient structure to perform "in communication with both said cell phone functionality and said RF communication functionality, operable to switch a communication path established on one of said cell phone functionality and said RF communication functionality, with another communication path later established on the other of said cell phone functionality and said RF communication functionality."

126. As such, I understand that the term "an automatic switch over module, in communication with both said cell phone functionality and said RF communication functionality, operable to switch a communication path established on one of said cell phone functionality and said RF communication functionality, with another communication path later established on the other of said cell phone functionality and said RF communication functionality" must be construed as a means-plus-function term. A POSITA would understand this means-plus-function term to recite the function "in communication with both said cell phone functionality

and said RF communication functionality, operable to switch a communication path established on one of said cell phone functionality and said RF communication functionality, with another communication path later established on the other of said cell phone functionality and said RF communication functionality."

127. As explained above, a POSITA would understand that the structure to implement the claimed function includes a general purpose computer (e.g., microprocessor) programmed to perform the functionality.

128. I disagree with BNR's statement that "[a] POSA would know this is a structure for RF communications through a genus of RF communication types well known in the art." BNR's proposed construction fails to recognize that a POSITA would understand that the claimed multimode cell phone includes a general purpose computer (e.g., microprocessor) programmed to perform wireless communications.

129. To disclose sufficient structure for a general purpose computer, I understand that the specification must disclose the algorithm for performing the claimed functions. No algorithm is disclosed by the '156 Patent to explain how the "in communication with . . ." function is to be performed by a general purpose computer. Although a POSITA might be able to create various algorithms to program a general purpose computer to implement the "in communication with . . . " function, the specification fails to disclose an algorithm for doing so.

130. BNR states that structure is found in the specification at "Figs. 1, 3, Col. 3:48–4:49; 4:54–5:62; 6:3–55; 6:60–8:5," but provides no further details. It is not apparent from these citations what BNR is identifying as structure. Based on my review, no algorithm for performing the "in communication with . . ." function is disclosed by the information BNR cited. For example, to the extent that BNR contends "step 210" ('156 Patent, 5:1–3) is structure for performing the claimed function, it is my opinion that "step 210" does not identify an algorithm to a

POSITA. "Step 210" describes functionality performed by the user of the far end telephone: "the user of the far end telephone 150 accepts the newly incoming telephone call." In other words, "step 210" fails to describe an algorithm for performing the claimed function on the claimed multimode cell phone.

131. As another example, to the extent that BNR contends "step 212" (*id*. at 5:4–6) is structure for performing the claimed function, it is my opinion that "step 212" does not identify an algorithm to a POSITA. "Step 212" describes a result: "the old communication path (in this case the cordless telephone call) is dropped." "Step 212" fails to disclose how the "old communication path" is dropped, and thus, fails to disclose to a POSITA an algorithm for performing the claimed function.

132. Accordingly, it is my opinion that a POSITA would understand that the "an automatic switch over module, in communication with both said cell phone functionality and said RF communication functionality, operable to switch a communication path established on one of said cell phone functionality and said RF communication functionality, with another communication path later established on the other of said cell phone functionality and said RF communication functionality" term is indefinite for lack of structure to perform the "in communication with . . ." function.

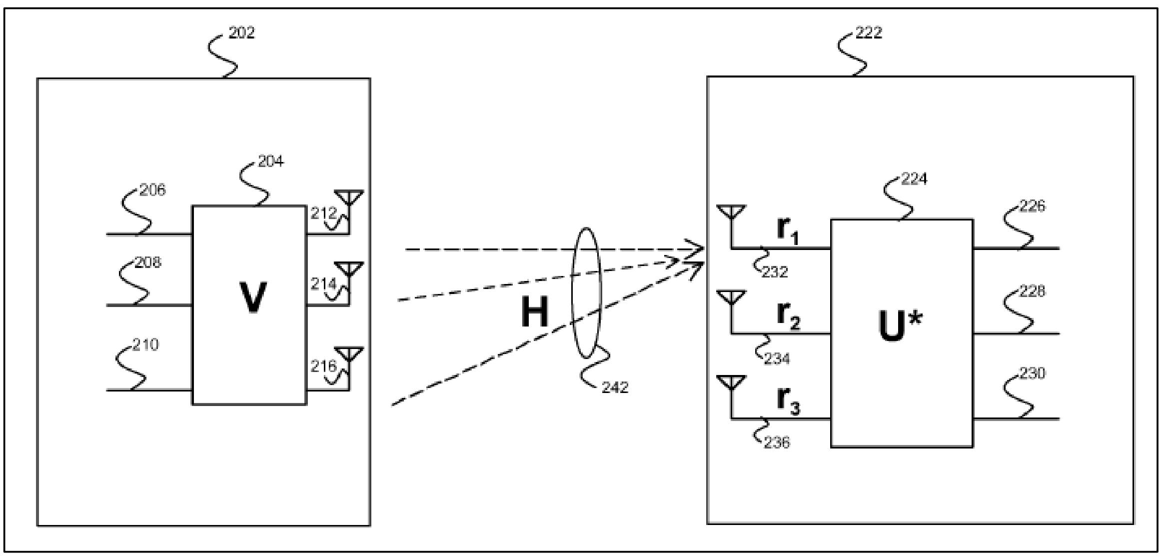
VII. The ’450 Patent

A. Summary

133. U.S. Patent No. 7,957,450 to Christopher J. Hansen, et al. ("the ’450 Patent"), is entitled "Method and System for Frame Formats for MIMO Channel Measurement Exchange" and was issued on June 7, 2011.

134. The ’450 Patent relates to wireless communications using beamforming, which is illustrated by the exemplary diagram of Figure 2 shown below. ’450 Patent, 11:32–33. Figure 2 shows "a transmitting mobile terminal 202,

a receiving mobile terminal 222, and a plurality of RF channels 242." *Id*. at 11:34–36. The signal transmitted by each antenna may be weighted by the transmit filter coefficient block V, in which V is represented by a matrix. *Id*. at 11:41–54. The receiving terminal includes a receiver filter coefficient block U*. *Id*. at 11:55–59. "The characteristics of the plurality of RF channels 242 utilized for communication between the transmitting mobile terminal 202, and the receiving mobile terminal 222 may be represented mathematically by a transfer coefficient matrix H." *Id*. at 11:61–65.



135. The '450 Patent relates to "feedback mechanisms by which a receiving mobile terminal may feedback information to a transmitting mobile terminal to assist the transmitting mobile terminal in adapting signals which are sent to the receiving mobile terminal." *Id*. at 1:30–34. In one embodiment, the specification discloses that the transmitting mobile terminal may receive feedback information comprising a full channel estimate matrix as computed by a receiving mobile terminal." *Id*. at 8:25–27. "Alternatively, the transmitting mobile terminal may receive feedback

information comprising decomposition matrices that were derived from a full channel estimate matrix." *Id*. at 8:28–30. The '450 Patent discloses that singular value decomposition (SVD) may be used to produce the decomposition matrices, thus reducing the quantity of feedback information:

> [A] receiving mobile terminal may perform a singular value decomposition (SVD) on the channel estimate matrix, and subsequently transmit SVD-derived feedback information to the transmitting mobile terminal. Utilizing SVD may increase the amount of computation required at the receiving mobile terminal but may reduce the quantity of information which is transmitted to the transmitting mobile terminal via the RF channel in comparison to transmitting the entire channel estimate matrix.

Id. at 7:67–8:10.

B. Person of Ordinary Skill in the Art ("POSITA")

136. In order to determine the characteristics of a person of ordinary skill in the art of the '450 Patent, I have used December 14, 2004 as the relevant time frame. My understanding is that this is the filing date of the provisional application to which the '450 Patent claims priority. For purposes of this statement, any reference to the filing date of the '450 Patent is intended to refer to this December 14, 2004 priority date of the provisional application to which the '450 Patent claims priority. (I have not been asked to opine on whether the provisional application is sufficient to establish the priority date for the '450 Patent; I am using this date in the following analysis because that is the priority date alleged by BNR.)

137. In determining the characteristics of a person of ordinary skill for the '450 Patent, I have considered the state of the art of wireless mobile communication systems at that time, the types of problems encountered with signal fading, and the solutions that then existed such as antenna systems, including MIMO, and beamforming techniques. I have also considered the then-existing technology for

wireless communication systems, such as cellular radio systems and wireless local area network systems (e.g., IEEE 802.11 Wi-Fi systems), including the sophistication of the technology involved. I have also considered the education and experience of those working in the field at that time. I have also considered my personal knowledge and experience with the field at that time, including those I worked and interacted with regarding wireless mobile communication systems. I have also considered the knowledge, education, and experience of those in academia and industry at that time that were working, innovating, or performing research in the field of wireless mobile communication systems, and in particular, techniques to address signal fading problems.

138. It is my opinion that a POSITA for the ’450 Patent at the time of this filing date would have had a Bachelor’s degree in Electrical Engineering, Computer Engineering, Computer Science, or a related field, and at least 2 to 4 years of experience in the field of wireless communication, or a person with equivalent education, work, or experience in this field.

C. Construction of the Disputed Terms in the ’450 Patent

139. I have been asked to opine on the meaning of two pairs of claim terms in the ’450 Patent: (a) “channel estimate matrices”; “matrix based on the/said plurality of channel estimates,” and (b) “coefficients derived from performing a singular value matrix decomposition (SVD)”; “coefficients from performing a singular value matrix decomposition (SVD).”

140. For my analysis, I have reviewed and considered the ’450 Patent’s specification, claims, and prosecution history. Based on this intrinsic evidence, I have interpreted these claim terms as they would have been understood by a POSITA as of the filing date of the ’450 Patent as explained below. I understand that BNR

has not identified extrinsic support to establish the meaning of these terms, aside from the possible (but not yet disclosed) testimony of its expert.

a. *"channel estimate matrices";*

"matrix based on the/said plurality of channel estimates"

'450 Patent Claim Term	BNR's Proposed Construction	Defendants' Proposed Construction
"channel estimate matrices"; "matrix based on the/said plurality of channel estimates"	Plain and ordinary meaning. In the alternative, to the extent the Court determines that a specific construction is warranted, BNR proposes: "one or more matrices that is based on an SVD decomposition of the estimates of the values of H(t)"	"matrix H_{est} for tones of different frequencies, where H_{est} contains estimates of the true values of H(t)"

Joint Claim Construction Worksheet, Appendix A at 22–28.

141. The term "channel estimate matrices" is used in claims 1, 2, 3, 11, 12, and 13. The term "matrix based on the plurality of channel estimates" is used in claim 21. The term "matrix based on said plurality of channel estimates" is used in claim 22. Notably, these terms are similar and should therefore be construed to have the same meaning.

142. It is my opinion that, at the time of the filing of the '450 Patent, a POSITA would understand these terms to mean "matrix H_{est} for tones of different frequencies, where H_{est} contains estimates of the true values of H(t)," as Defendants

propose. My opinion is supported by the disclosures in the ’450 Patent as I explain in the following paragraphs.

143. In the background section, the specification states that an RF channel between a transmitting mobile terminal and a receiving mobile terminal may be represented by “a transfer system function, H.” ’450 Patent, 3:53–57. “The relationship between a time varying transmitted signal, x(t), a time varying received signal, y(t), and the systems function may be represented as shown in equation [1]:

$y(t)=H\times x(t)+n(t)$, where equation[1]

n(t) represents noise which may be introduced as the signal travels through the communications medium and the receiver itself. In MIMO systems, the elements in equation[1] may be represented as vectors and matrices.” *Id.* at 3:57–66.

144. Due to signal fading effects that may be time varying in nature, the transfer function H may be represented as a function of time, H(t). *Id.* at 4:5–9. The specification explains that, for IEEE 802.11 systems, the receiving terminal may compute H(t) for each frame of information received from a transmitting terminal. *Id.* at 4:10–14. The specification explicitly identifies H(t) as a “channel estimate matrix,” which **contains “estimate[s] of the ‘true’ values of H(t)**.”

> The computations which are performed at the receiving mobile terminal may constitute an estimate of the “true” values of H(t) and may be known as “channel estimates”. For a frequency selective channel there may be a set of H(t) coefficients for each tone that is transmitted via the RF channel. To the extent that H(t), which may be referred to as the “channel estimate matrix”, changes with time and to the extent that the transmitting mobile terminal fails to adapt to those changes, information loss between the transmitting mobile terminal and the receiving mobile terminal may result.

Id. at 4:14–24.

145. The patent discloses that the transfer function H may be different for the forward channel (downlink direction) and the reverse channel (uplink direction). Accordingly, the receiving terminal may compute a "**reverse channel estimate matrix, $\mathbf{H_{up}}$**," and the transmitting terminal may compute a "**forward channel estimate matrix, $\mathbf{H_{down}}$**." *Id*. at 4:66–5:7.

146. The patent discloses an embodiment of the invention utilizing singular value decomposition (SVD) that describes a "**full channel estimate matrix** which is computed by a receiving mobile terminal, $\mathbf{H}_{est}$." *Id*. at 8:52–65.

> H_{est}, may be represented by its SVD:
>
> $H_{est} = USV^H$, where equation[2]
>
> H_{est} may be a complex matrix of dimensions $N_{rx} \times N_{tx}$, where N_{rx} may be equal to the number of receive antenna at the receiving mobile terminal, and N_{tx} may be equal to the number of transmit antenna at the transmitting mobile terminal, U may be an orthonormal complex matrix of dimensions $N_{rx}N_{rx}$, S may be a diagonal real matrix of dimensions $N_{rx} \times N_{tx}$, and V may be an orthonormal complex matrix of dimensions $N_{tx} \times N_{tx}$ with V^H being the Hermitian transform of the matrix V. The singular values in the matrix S may represent the square roots of the Eigenvalues for the matrix H_{est}, U may represent the left singular vectors for the matrix H_{est} where the columns of U may be the Eigenvectors of the matrix product $H_{est}H_{est}^H$, and V^H may represent the right singular vectors for the matrix H_{est} where the columns of V may be the Eigenvectors of the matrix product $H_{est}^H H_{est}$.

Id. at 8:54–9:4.

147. The patent further discloses that the matrix H_{est} for tones of different frequencies:

> For an RF channel, **$\mathbf{H}_{est}$ may be different for tones of different frequencies** that are transmitted via the RF channel. Thus, a plurality of **channel estimate matrices**, H_{est}, may be computed

> to account for each tone which may be transmitted via the RF channel.

Id. at 9:33–37. Thus, for wireless systems employing different frequencies, a receiving terminal would compute an H_{est} matrix for tones of different frequencies, such as in an IEEE 802.11 based system. *See id*. at 3:14–18 (discussing "orthogonal frequency division multiplexing (OFDM), in which each of the plurality of signals is modulated by a different frequency carrier signal prior to mapping and multiplicative scaling"); *id*. at 4:10–14 (discussing MIMO systems operating in accordance with IEEE 802.11).

148. These passages show that the '450 Patent consistently refers to a "channel estimate matrix" as a matrix H.[4] Similarly, the claim term "matrix based on the/said plurality of channel estimates" must also refer to a matrix H.

149. As the patent explains, a matrix H computed by a receiving terminal "constitute[s] an estimate of the 'true' values of H(t)" (*id*. at 4:14–17), and therefore, the patent uses the notation "H_{est}" to indicate that the matrix H is "an estimate" of the channel (*e.g.*, *id*. at 6:52–56).

150. Because the transfer function H for the RF channel may be "different for tones of different frequencies," a receiving terminal may compute H_{est} "to account for each tone." *Id*. at 9:33–36. The patent describes and claims these H_{est} matrices for each tone as "a plurality of channel estimate matrices, H_{est}." *Id*.

151. As further support for Defendants' construction, I note that the proposed construction is not limited to a specific embodiment, nor does it exclude any of the embodiments disclosed by the specification.

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[4] The '862 Patent, which identifies its inventors as two of the '450 Patent inventors, also refers to an estimated "channel response" as a matrix "H." '862 Patent, 3:14–33, 13:36–53.

152. It is my opinion that BNR's proposed construction is incorrect. First, BNR contends that these terms have a plain and ordinary meaning, without specifying what it contends that "plain and ordinary meaning" is. To a POSITA, the transfer function, *H*, shown as part of equation [1] of the '450 patent, is what defines the channel, which lies between the transmitter and the receiver. As shown in equation [1], when the transmitter transmits signal *x(t)*, the channel modifies it with *H*, which characterizes the channel, and the receiver receives signal *Hx(t)* together with noise *n(t)*, which corrupts the received signal. This equation is widely known among the POSITAs, which is taught as part of an introductory communication theory course at the undergraduate level. Personally, I have taught such a course for many years, starting from early 1990 shortly after I joined the faculty at Washington University. A POSITA would understand this to meaning be consistent with Defendants' proposed construction.

153. Second, BNR's alternative proposed construction requires a channel estimate matrix (or matrices) to be "based on an SVD decomposition of the estimates of the values of H(t)." However, that contradicts the specification, which discloses that the channel estimate matrix is not based on an SVD decomposition of a matrix H, but instead that an SVD operation is performed ***on*** a channel estimate matrix H:

> When computing the SVD a plurality of techniques may be utilized in performing SVD reduction **on the full channel estimate matrix**.

Id. at 8:49–52. Another passage in the brief summary of the invention section also confirms that decomposition of the channel estimates is performed to derive feedback information:

> Feedback information may be derived from mathematical matrix decomposition **of the channel estimates**.

Id. at 6:44–45. Defendants' proposed construction is consistent with the patent specification, which consistently refers to a channel estimate matrix (or matrices) as a matrix H.

154. Third, BNR's alternative proposed construction incorporates into the terms to be construed an SVD limitation that is separately claimed in the independent claims into the terms to be construed, while ignoring other claimed limitations. For example, claim 1 recites a plurality of channel estimate matrices "based on signals received by a mobile terminal," and further requires that said matrices "comprise coefficients derived from performing a singular value matrix decomposition (SVD) on said received signals." Independent claims 11, 21, and 22 recite similar limitations. BNR's construction is improper because further limitations are expressly recited in the claims, and thus should not be duplicated in construing the term.

155. Accordingly, it is my opinion that a POSITA would understand the terms "channel estimate matrices" and "matrix based on the/said plurality of channel estimates" to mean "matrix H_{est} for tones of different frequencies, where H_{est} contains estimates of the true values of H(t)."

b. *"coefficients derived from performing a singular value matrix decomposition (SVD)";*
"coefficients from performing a singular value matrix decomposition (SVD)"

'450 Patent Claim Term	BNR's Proposed Construction	Defendants' Proposed Construction
"coefficients derived from	Plain and ordinary meaning.	"values in the matrices U, S, or V^H, where H_{est}=USV^H"

’450 Patent Claim Term	BNR’s Proposed Construction	Defendants’ Proposed Construction
performing a singular value matrix decomposition (SVD)”; “coefficients from performing a singular value matrix decomposition (SVD)”	In the alternative, to the extent the Court determines that a specific construction is warranted, BNR proposes: “values derived from a singular value decomposition”	

Joint Claim Construction Worksheet, Appendix A at 29–33.

156. The term “coefficients derived from performing a singular value matrix decomposition (SVD” is used in claims 1, 11, and 22. The term “coefficients from performing a singular value matrix decomposition (SVD)” is used in claim 21. Notably, the terms are nearly identical.

157. It is my opinion that, at the time of the filing of the ’450 Patent, a POSITA would understand these terms to mean “values in the matrices U, S, or V^H, where H_{est}=USV^H” as Defendants propose. My opinion is supported by the disclosures in the ’450 Patent as I explain in the following paragraphs.

158. The patent discloses that “SVD is a method which may reduce the quantity of channel feedback information which is transmitted between a receiving mobile terminal and a transmitting mobile terminal.” *Id*. at 8:45–47. To implement this method, the receiving terminal “perform[s] SVD reduction on the full channel estimate matrix.” *Id*. at 8:49–52. As explained above, and in the patent, H_{est} is the “full channel estimate matrix which is computed by a receiving mobile terminal.” *Id*. at 8:52–65. The patent specification consistently describes the claimed SVD techniques in terms of performing an SVD on the “channel estimate matrix” (*id*. at

7:67–8:5) and in performing the SVD specified by equation [2] (*id*. at 8:52–65, 9:21–24, 9:37–42).

159. In equation [2], the patent explicitly discloses that the mathematical expression for the SVD of the matrix H_{est} is:

H_{est}=USV^H.

Id. at 8:52–65. A POSITA would understand from linear algebra that the computed matrices U, S, and V^H, which are derived from the matrix H_{est}, include coefficients. The patent confirms this understanding as well:

> In another embodiment of the invention, a further reduction in the quantity of information that is transmitted in feedback information may be achieved by **computing a plurality of SVD on H_{est} as in equation[2]**, and averaging the **coefficient values in matrices V^H and S** over a plurality of tones.

Id. at 9:37–42.

160. It is my opinion that BNR's proposed construction is incorrect. First, BNR contends that these terms have a plain and ordinary meaning, without specifying what that "plain and ordinary meaning" is. In addition, the patent consistently refers to the SVD specified by equation [2], where H_{est}=USV^H. No other SVD is disclosed.

161. Second, BNR's alternative proposed construction repeats the term to be construed, with the exception of the construing the term "coefficients" to mean "values." As explained above, the specification only discloses SVD operations using the equation [2] that results in the "values" in the matrices U, S, and V^H.

162. Accordingly, it is my opinion that a POSITA would understand the terms "coefficients derived from performing a singular value matrix decomposition (SVD" and "coefficients from performing a singular value matrix decomposition (SVD)" to mean "values in the matrices U, S, or V^H, where H_{est}=USV^H."

VIII. The ’862 Patent

A. Summary

163. U.S. Patent No. 8,416,862 to Carlos Aldana, et al. (“the ’862 Patent”), is entitled “Efficient Feedback of Channel Information in a Closed Loop Beamforming Wireless Communication System” and was issued on April 9, 2013.

164. The ’862 Patent relates to wireless communications using beamforming. ’862 Patent, 1:20–22. “FIG. 6 is a schematic block diagram of a beamforming wireless communication where H=UDV* (H—represents the channel, U is the receiver beamforming unitary matrix, and V* is the conjugate of the transmitter beamforming unitary matrix.” *Id*. at 12:47–51.

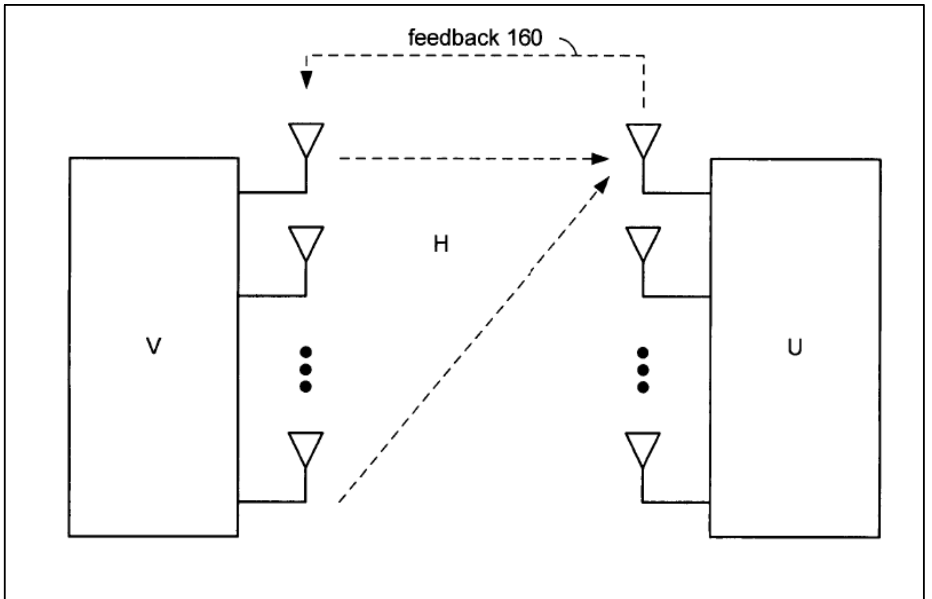

FIG. 6

165. In the background section, the specification explains that a receiver must provide feedback information “for a transmitter to properly implement beamforming (i.e., determine the beamforming matrix [V]).” *Id*. at 3:14–19. “One

approach for sending feedback from the receiver to the transmitter is for the receiver to determine the channel response (H) and to provide it as the feedback information." *Id*. at 3:19–22. Alternatively, "the receiver may decompose the channel using singular value decomposition (SVD) and send information relating only to a calculated value of the transmitter's beamforming matrix (V) as the feedback information. In this approach, the receiver calculates (V) based on H=UDV*, where H is the channel response, D is a diagonal matrix, and U is a receiver unitary matrix." *Id*. at 3:26–33. The patent explains that each of these prior art methods results in the size of the feedback information being too large for practical applications. *Id*. at 3:22–25, 3:33–35.

166. The '862 Patent states that it discloses the following method for feeding back transmitter beamforming information:

> A method for feeding back transmitter beamforming information from a receiving wireless communication device to a transmitting wireless communication device includes a receiving wireless communication device receiving a preamble sequence from the transmitting wireless device. The receiving wireless device estimates a channel response based upon the preamble sequence and then determines an estimated transmitter beamforming unitary matrix based upon the channel response and a receiver beamforming unitary matrix. The receiving wireless device then decomposes the estimated transmitter beamforming unitary matrix to produce the transmitter beamforming information and then wirelessly sends the transmitter beamforming information to the transmitting wireless device. The receiving wireless device may transform the estimated transmitter beamforming unitary matrix using a QR decomposition operation such as a Givens Rotation operation to produce the transformer beamforming information.

'862 Patent, Abstract.

B. Person of Ordinary Skill in the Art ("POSITA")

167. In order to determine the characteristics of a person of ordinary skill in the art of the '862 Patent, I have used April 21, 2005 as the relevant time frame. My understanding is that this is the filing date of the earliest provisional application to which the '862 Patent claims priority. For purposes of this statement, any reference to the filing date of the '862 Patent is intended to refer to this April 21, 2005 priority date of the provisional application to which the '862 Patent claims priority. (I have not been asked to opine on whether the provisional application is sufficient to establish the priority date for the '862 Patent; I am using this date in the following analysis because that is the priority date alleged by BNR.)

168. In determining the characteristics of a person of ordinary skill for the '862 Patent, I have considered the state of the art of wireless mobile communication systems at that time, the types of problems encountered with signal fading, and the solutions that then existed such as antenna systems, including MIMO, and beamforming techniques. I have also considered the then-existing technology for wireless communication systems, such as cellular radio systems and wireless local area network systems (e.g., IEEE 802.11 Wi-Fi systems), including the sophistication of the technology involved. I have also considered the education and experience of those working in the field at that time. I have also considered my personal knowledge and experience with the field at that time, including those I worked and interacted with regarding wireless mobile communication systems. I have also considered the knowledge, education, and experience of those in academia and industry at that time that were working, innovating, or performing research in the field of wireless mobile communication systems, and in particular, techniques to address signal fading problems.

169. It is my opinion that a POSITA for the ’862 Patent at the time of this filing date would have had a Bachelor’s degree in Electrical Engineering, Computer Engineering, Computer Science, or a related field, and at least 2 to 4 years of experience in the field of wireless communication, or a person with equivalent education, work, or experience in this field.

C. Construction of the Disputed Terms in the ’862 Patent

170. I have been asked to opine on the meaning of three claim terms in the ’862 Patent: (a) “decompose the estimated transmitter beamforming unitary matrix (V) to produce the transmitter beamforming information,” (b) “a baseband processing module operable to: receive a preamble sequence carried by the baseband signal; estimate a channel response based upon the preamble sequence; determine an estimated transmitter beamforming unitary matrix (V) based upon the channel response and a receiver beamforming unitary matrix (U); decompose the estimated transmitter beamforming unitary matrix (V) to produce the transmitter beamforming information; and form a baseband signal employed by the plurality of RF components to wirelessly send the transmitter beamforming information to the transmitting wireless device,” and (c) “the baseband processing module is operable to: produce the estimated transmitter beamforming unitary matrix (V) in Cartesian coordinates; and convert the estimated transmitter beamforming unitary matrix (V) to polar coordinates.”

171. For my analysis, I have reviewed and considered the ’862 Patent’s specification, claims, and prosecution history. Based on this intrinsic evidence, I have interpreted these claim terms as they would have been understood by a POSITA as of the filing date of the ’862 Patent as explained below. For the two “baseband

processing module" terms, I have also reviewed and considered the three publications that BNR identified as extrinsic evidence.[5]

a. *"decompose the estimated transmitter beamforming unitary matrix (V) to produce the transmitter beamforming information"*

'862 Patent Claim Term	BNR's Proposed Construction	Defendants' Proposed Construction
"decompose the estimated transmitter beamforming unitary matrix (V) to produce the transmitter beamforming information"	"factor the estimated transmitter beamforming unitary matrix (V) to produce a reduced number of quantized coefficients"	"factor the estimated transmitter beamforming unitary matrix (V) to produce a reduced set of angles"

Joint Claim Construction Worksheet, Appendix A at 14–15.

172. The term "decompose the estimated transmitter beamforming unitary matrix (V) to produce the transmitter beamforming information" is used in claim 9.

[5] BNR identified three publications as extrinsic evidence to support their proposed construction for the "baseband processing module …" terms:

> Wireless vs. Wired. How Software Define Radio technology addresses issues related to the use of wireless networks when compared to a wired solution White Paper, Lexycom Technologies, Inc. (May 2005). See BNR SDCA00037995 – BNR-SDCA00038005.
>
> Igor S. Simic, Evolution of Mobile Base Station Architectures, Microwave Review at 31 (June 2007). See BNR-SDCA00037973 – BNR-SDCA00037979.
>
> Rajeesh Kutty, A Simple Baseband Processor for RF Transceivers, Analog Devices. See BNR-SDCA00000037967 – BNR-SDCA00037972.

173. It is my opinion that, at the time of the filing of the ’862 Patent, a POSITA would understand this term to mean “factor the estimated transmitter beamforming unitary matrix (V) to produce a reduced set of angles,” as Defendants propose. My opinion is supported by the disclosures in the ’862 Patent as I explain in the following paragraphs.

174. BNR and the Defendants agree on the first part of the construction of this term. That is, “decompose the estimated transmitter beamforming unitary matrix (V) to produce . . .” means “factor the estimated transmitter beamforming unitary matrix (V) to produce . . .”. According to the patent specification, “[t]he receiving wireless device may transform the estimated transmitter beamforming unitary matrix using a QR decomposition operation such as a Givens Rotation operation to produce the [transmitter] beamforming information.”[6] ’862 Patent, Abstract. QR decomposition, which refers to a linear algebra technique to decompose a given matrix into the product of two other matrices (Q and R), is also sometimes referred to as QR factorization. Based on this understanding, I agree that a POSITA would understand the term “decompose” to mean “factor,” and therefore, agree that the first part of this term means “factor the estimated transmitter beamforming unitary matrix (V) to produce . . .”

175. The patent discloses the use of a Givens Rotation operation in the context of two embodiments “for providing beamforming feedback information from a receiver to a transmitter,” which are illustrated as Figures 7 and 8. *Id*. at 4:15–20.

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[6] The language in the Abstract which identified “*transformer* beamforming information” appears to be a typographical error for what was presumably intended to reference “*transmitter* beamforming information.” The term “transformer” is not used anywhere else in the ’862 patent.

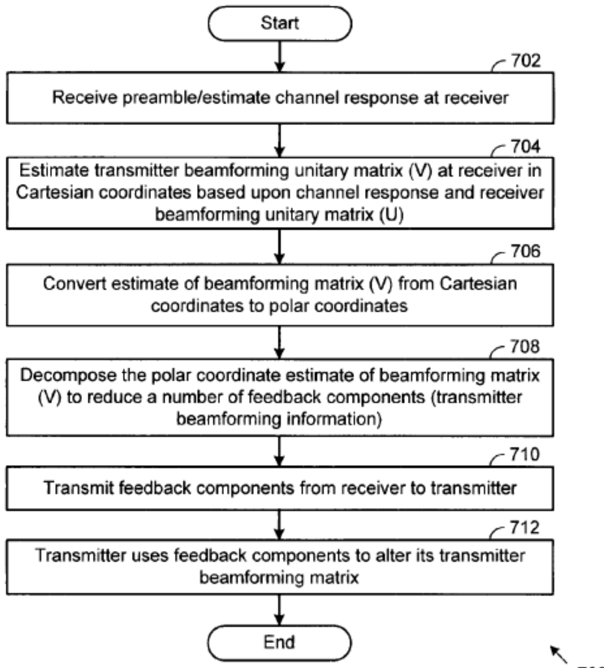

Start
702
Receive preamble/estimate channel response at receiver
704
Estimate transmitter beamforming unitary matrix (V) at receiver in Cartesian coordinates based upon channel response and receiver beamforming unitary matrix (U)
706
Convert estimate of beamforming matrix (V) from Cartesian coordinates to polar coordinates
708
Decompose the polar coordinate estimate of beamforming matrix (V) to reduce a number of feedback components (transmitter beamforming information)
710
Transmit feedback components from receiver to transmitter
712
Transmitter uses feedback components to alter its transmitter beamforming matrix
End
700

FIG. 7

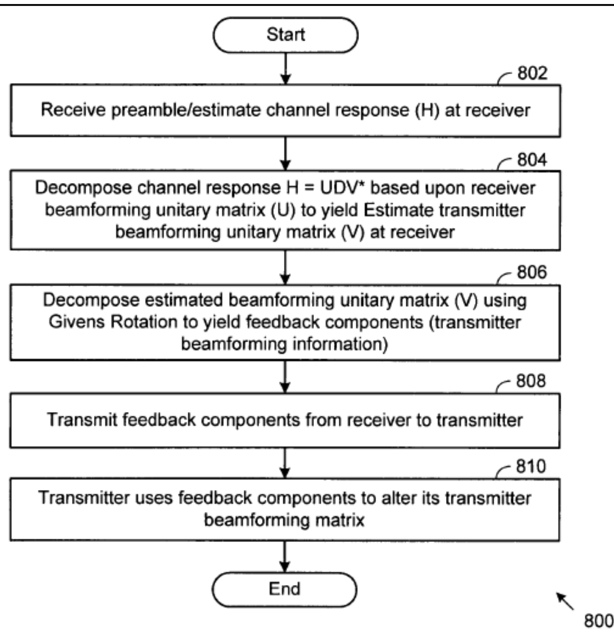

Start
802
Receive preamble/estimate channel response (H) at receiver
804
Decompose channel response H = UDV* based upon receiver beamforming unitary matrix (U) to yield Estimate transmitter beamforming unitary matrix (V) at receiver
806
Decompose estimated beamforming unitary matrix (V) using Givens Rotation to yield feedback components (transmitter beamforming information)
808
Transmit feedback components from receiver to transmitter
810
Transmitter uses feedback components to alter its transmitter beamforming matrix
End
800

FIG. 8

176. Step 708 of the embodiment of Figure 7 discloses a Givens Rotation operation to decompose "the estimated transmitter beamforming unitary matrix (V)." *Id*. at 13:58–65. The matrix (V) to be decomposed is in the form of polar coordinates (which includes angles), after having been converted from Cartesian coordinates in earlier step 706. *Id*. at 13:54–58. The patent explains that the Givens Rotation operation reduces the set of angles in the matrix (V):

> The Givens Rotation relies upon the observation that, with the condition of V*V=VV*=I, **some of angles of the Givens Rotation are redundant**. With a decomposed matrix form for the estimated transmitter beamforming matrix (V), **the set of angles fed back to the transmitting wireless device are reduced.**

Id. at 13:65–14:3.

177. Step 806 of the embodiment of Figure 8 similarly discloses using a Givens Rotation "to produce the transmitter beamforming information":

> With the estimated transmitter beamforming unitary matrix (V) determined, the receiving wireless device then decomposes the estimated transmitter beamforming unitary matrix (V) using a Givens Rotation **to produce the transmitter beamforming information** (step 806). **The products of this Givens Rotation are the transmitter beamforming information.**

Id. at 14:31–37.

178. Consistent with these two embodiments, the patent explains that the transmitter may regenerate the V matrix from the reduced set of angles produced using a Givens Rotation. For example, for a 2x2 MIMO communication (i.e., 2 transmit antennas and 2 receive antennas), the transmitter does not need four angles from the matrix (V) (ψ_1, Φ_1, ψ_2, and Φ_2), but instead "may regenerate V per each tone" using just two angles (ψ_1, Φ_1). *Id*. at 10:38–60.

179. Based on these passages from the specification, a POSITA would understand that the claimed decomposition of the estimated transmitter beamforming unitary matrix (V) produces "a reduced set of angles."

180. It is my opinion that BNR's proposed construction is incorrect. The decomposition of the estimated transmitter beamforming unitary matrix (V) does not produce "a reduced number of quantized coefficients." First, the specification explains the basis for using a Givens Rotation is with respect to "angles," not coefficients. *Id*. at 13:65–14:3 ("some of angles of the Givens Rotation are redundant"). Second, a POSITA would understand from linear algebra that neither a Givens Rotation nor any QR decomposition operation produces "quantized" values. Quantization refers to a transformation of data into integer values. However, the claim language is clear in that the "transmitter beamforming information" is produced by "decompos[ing] the estimated transmitter beamforming unitary matrix (V)," not by quantizing data.

181. Accordingly, it is my opinion that a POSITA would understand the terms "decompose the estimated transmitter beamforming unitary matrix (V) to produce the transmitter beamforming information" to mean "factor the estimated transmitter beamforming unitary matrix (V) to produce a reduced set of angles."

b. "a baseband processing module operable to: receive a preamble sequence carried by the baseband signal; estimate a channel response based upon the preamble sequence; determine an estimated transmitter beamforming unitary matrix (V) based upon the channel response and a receiver beamforming unitary matrix (U); decompose the estimated transmitter beamforming unitary matrix (V) to produce the transmitter beamforming information; and form a baseband

signal employed by the plurality of RF components to wirelessly send the transmitter beamforming information to the transmitting wireless device"

'862 Patent Claim Term	BNR's Proposed Construction	Defendants' Proposed Construction
"a baseband processing module operable to: receive a preamble sequence carried by the baseband signal; estimate a channel response based upon the preamble sequence; determine an estimated transmitter beamforming unitary matrix (V) based upon the channel response and a receiver beamforming unitary matrix (U); decompose the estimated transmitter beamforming unitary matrix (V) to produce the transmitter beamforming information; and	Not a 112 ¶ 6 claim element – "baseband processing module" is not a nonce word. Instead, a baseband processing module is itself sufficient structure. A POSA would know this is a baseband processor implemented in ASIC, FGPA, logic circuits, or the like in RF communication hardware. In the alternative, to the extent the Court determines that this claim is governed by 112 ¶ 6, BNR proposes the following Function and Structure, and disagrees that the term is indefinite for lack of corresponding structure: <u>Function</u>: "receive a preamble sequence carried by the baseband signal;	This is a 112 ¶ 6 claim element. <u>Function</u>: "receive a preamble sequence carried by the baseband signal; estimate a channel response based upon the preamble sequence;

’862 Patent Claim Term	BNR’s Proposed Construction	Defendants’ Proposed Construction
form a baseband signal employed by the plurality of RF components to wirelessly send the transmitter beamforming information to the transmitting wireless device”	estimate a channel response based upon the preamble sequence; determine an estimated transmitter beamforming unitary matrix (V) based upon the channel response and a receiver beamforming unitary matrix (U); decompose the estimated transmitter beamforming unitary matrix (V) to produce the transmitter beamforming information; and form a baseband signal employed by the plurality of RF components to wirelessly send the transmitter beamforming information to the transmitting wireless device” <u>Structure</u>: Corresponding structure for the alleged function exists in at least the following portions of the patent specification, or their equivalents: Figs. 2-5, Col. 5:49–6:12, 6:37–7:20; 7:51–9:30; 9:31–13:35; 13:54–15:67.	determine an estimated transmitter beamforming unitary matrix (V) based upon the channel response and a receiver beamforming unitary matrix (U); decompose the estimated transmitter beamforming unitary matrix (V) to produce the transmitter beamforming information; and form a baseband signal employed by the plurality of RF components to wirelessly send the transmitter beamforming information to the transmitting wireless device” <u>Structure</u>: Indefinite for lack of corresponding structure in the patent specification.

Joint Claim Construction Worksheet, Appendix A at 15–18.

182. The term "a baseband processing module operable to: receive a preamble sequence carried by the baseband signal; estimate a channel response based upon the preamble sequence; determine an estimated transmitter beamforming unitary matrix (V) based upon the channel response and a receiver beamforming unitary matrix (U); decompose the estimated transmitter beamforming unitary matrix (V) to produce the transmitter beamforming information; and form a baseband signal employed by the plurality of RF components to wirelessly send the transmitter beamforming information to the transmitting wireless device" is used in claim 9.

183. It is my opinion that, at the time of the filing of the '862 Patent, a POSITA would understand this term to be a means-plus-function term that is indefinite for lack of corresponding structure to perform every recited function, as Defendants propose. My opinion is supported by the disclosures in the '862 Patent as I explain in the following paragraphs.

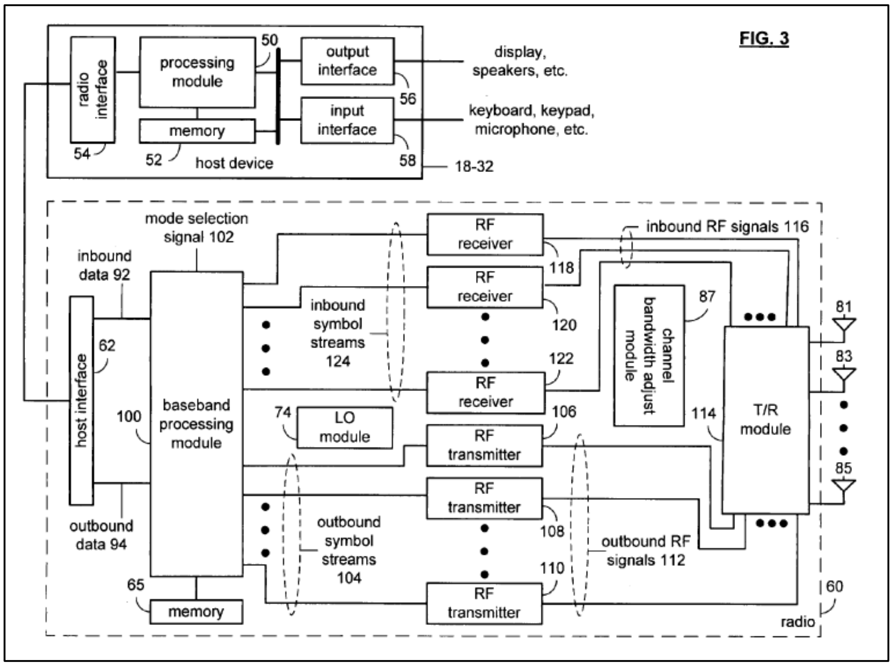
184. I understand that the "baseband processing module . . ." term may be construed as a means-plus-function term, despite not using the word "means," if that term recites function without reciting sufficient structure for performing that function. In my opinion, a POSITA would understand that the term "module" is used in the context of a "baseband processing module" as a nonce word, and does not identify sufficiently definite structure. Here, the limitation recites five functions—"receive," "estimate," "determine," "decompose," and "form." But, the claim limitation does not set forth sufficiently definite structure to perform these five functions.

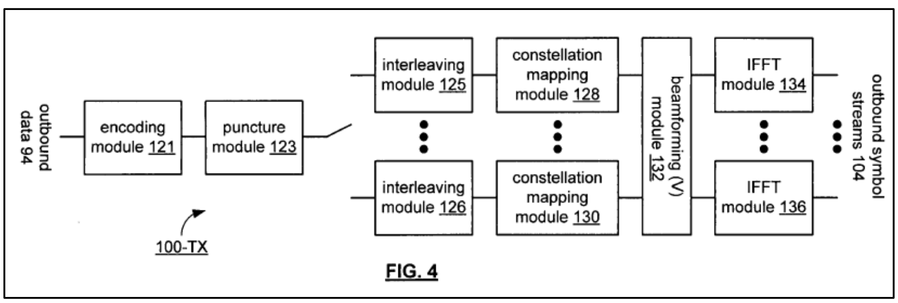
185. A POSITA would understand that the claim limitation includes a general purpose computer (e.g., microprocessor). But, that is not sufficient structure to perform the claimed functions. An off-the-shelf general purpose computer is not

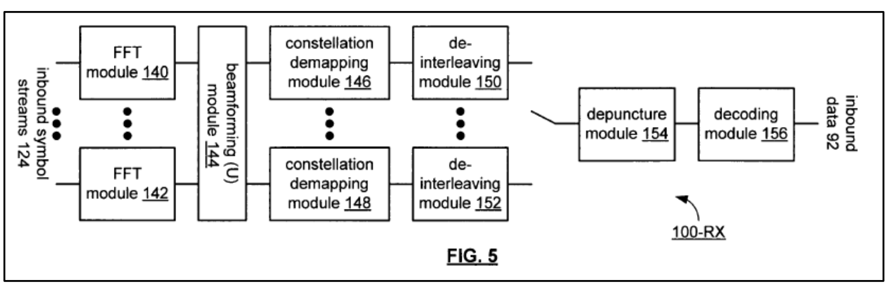
capable of performing the functions of the claim without special programming. Special programming is necessary for a general purpose computer to perform the "receive," "estimate," "determine," "decompose," and "form" functions.

186. As such, I understand that the "baseband processing module" term must be construed as a means-plus-function term. BNR and Defendants agree that the functions recited by this means-plus-function term are: "receive a preamble sequence carried by the baseband signal; estimate a channel response based upon the preamble sequence; determine an estimated transmitter beamforming unitary matrix (V) based upon the channel response and a receiver beamforming unitary matrix (U); decompose the estimated transmitter beamforming unitary matrix (V) to produce the transmitter beamforming information; and form a baseband signal employed by the plurality of RF components to wirelessly send the transmitter beamforming information to the transmitting wireless device." Based on my review of the language of claim 9, I also agree that a POSITA would understand these to be the recited functions.

187. In Figure 3, the specification illustrates a wireless communication device that include "baseband processing module 100." *Id*. at 7:51–56. Baseband processing module 100 is further illustrated in Figures 4 and 5. "Fig. 4 is a schematic block diagram of baseband transmit processing 100-TX within the baseband processing module 100 . . . ." *Id*. at 9:31–38. "FIG. 5 is a schematic block diagram of baseband receive processing 100-RX . . . ." *Id*. at 11:60–67.







188. The specification discloses that baseband processing module 100 is a "processing device" that "in combination with operational instructions stored in memory 65, executes digital receiver functions and digital transmitter functions." *Id.* at 7:56–59, 8:1–3. The specification identifies a list of exemplary "processing

devices," but explains that each processing device utilizes "operational instructions" stored in a memory:

> Such a processing device may be a microprocessor, micro-controller, digital signal processor, microcomputer, central processing unit, field programmable gate array, programmable logic device, state machine, logic circuitry, analog circuitry, digital circuitry, and/or any device that manipulates signals (analog and/or digital) **based on operational instructions**. The memory 65 may be a single memory device or a plurality of memory devices. Such a memory device may be a read-only memory, random access memory, volatile memory, non-volatile memory, static memory, dynamic memory, flash memory, and/or any device that stores digital information. Note that when the processing module 100 implements one or more of its functions via a state machine, analog circuitry, digital circuitry, and/or logic circuitry, the **memory storing the corresponding operational instructions** is embedded with the circuitry comprising the state machine, analog circuitry, digital circuitry, and/or logic circuitry.

Id. at 8:3–20.

189. A POSITA would understand that the specification's descriptions of "processing devices," which execute operational instructions, refers to a general purpose computer requiring specialized programming to function. Specifically, without specialized programming, a general purpose computer could not operate to "receive a preamble sequence carried by the baseband signal; estimate a channel response based upon the preamble sequence; determine an estimated transmitter beamforming unitary matrix (V) based upon the channel response and a receiver beamforming unitary matrix (U); decompose the estimated transmitter beamforming unitary matrix (V) to produce the transmitter beamforming information; and form a baseband signal employed by the plurality of RF components to wirelessly send the transmitter beamforming information to the transmitting wireless device," as is

required by the baseband processing module of claim 9. A POSITA would understand that these specialized functions were not performed by off-the-shelf "processing devices" (general purpose computers) at the time of the filing of the '862 Patent.

190. I disagree with BNR's statement in its proposed construction that the term is not a 112 ¶ 6 claim element because "[a] POSA would know this is a baseband processor implemented in ASIC, FGPA, logic circuits, or the like in RF communication hardware." As explained above, the specification states that the baseband processing module is a "processing device" that utilizes "operational instructions" stored in a memory. Even if a POSITA would know that the components BNR identifies (i.e., "ASIC, FPGA, logic circuits or the like in RF communication hardware") may be included among components used to implement a "baseband processor," BNR fails to recognize that a POSITA would understand that the implementation would include a general processing device that is specially programmed. This understanding is also consistent with the specification's explanation that the processing devices used to implement the "baseband processing module" execute operational instructions stored in memory. Thus, such components do not provide sufficient structure for the claimed "baseband processing module."

191. To disclose sufficient structure for a general purpose computer, I understand that the specification must disclose the algorithm for performing the claimed functions. Following is my analysis of (1) whether the specification discloses an algorithm, and (2) if so, whether that algorithm defines the structure of the claimed baseband processing module and makes the bounds of the claims understandable to a POSITA.

(1) receive a preamble sequence carried by the baseband signal

192. The specification fails to disclose sufficient structure for performing the "receive . . ." function.

193. In the context of steps 702 and 802 in the embodiments of Figures 7 and 8, the specification states:

> The method 700 commences with the receiving wireless communication device receiving a preamble sequence from the transmitting wireless device and estimating a channel response from the preamble sequence (step 702).

Id. at 13:37–40.

> The method 800 commences with the receiving wireless communication device receiving a preamble sequence from the transmitting wireless device and estimating a channel response (H) from the preamble sequence (step 802).

Id. at 14:21–24.

194. No algorithm is disclosed by these passages, or any other passages, for performing the claimed function: "receive a preamble sequence." BNR states that structure is found in the specification at "Figs. 2-5, Col. 5:49–6:12, 6:37–7:20; 7:51–9:30; 9:31–13:35; 13:54–15:67," but provides no further details. It is not apparent from these citations what BNR is identifying as structure. Based on my review, no algorithm for performing the "receive a preamble sequence" function is disclosed by the information BNR cited. Accordingly, it is my opinion that a POSITA would understand that the baseband processing module term is indefinite for lack of structure to perform the "receive a preamble sequence carried by the baseband signal" function.

(2) estimate a channel response based upon the preamble sequence

195. The specification fails to disclose sufficient structure for performing the "estimate . . ." function.

196. In the context of steps 702 and 802 of the embodiments of Figures 7 and 8, the specification states:

> Estimating the channel response includes comparing received training symbols of the preamble to corresponding expected training symbols using any of a number of techniques that are known in the art.

Id. at 13:40–44.

> Techniques similar/same as those described with reference to step 702 of FIG. 7 may be employed.

Id. at 14:24–26.

197. While the specification states that a "comparing" operation is involved, no algorithm is disclosed for performing the "estimate a channel response based upon the preamble sequence" function. BNR states that structure is found in the specification at "Figs. 2-5, Col. 5:49–6:12, 6:37–7:20; 7:51–9:30; 9:31–13:35; 13:54–15:67," but provides no further details. It is not apparent from these citations what BNR is identifying as structure. Based on my review, no algorithm for performing the "estimate a channel response based upon the preamble sequence" function is disclosed by the information BNR cited. Accordingly, it is my opinion that a POSITA would understand that the baseband processing module term is indefinite for lack of structure to perform the "estimate a channel response based upon the preamble sequence" function.

(3) determine an estimated transmitter beamforming unitary matrix (V) based upon the channel response and a receiver beamforming unitary matrix (U)

198. The specification discloses sufficient structure for the "determine . . ." function in the form of an algorithm that defines the structure of the claimed

baseband processing module and makes the bounds of the claims understandable to a POSITA, as explained below.

199. The specification discloses the "estimate a channel response . . ." function in the context of steps 704 and 804 of the embodiments of Figures 7 and 8:

> The receiving wireless device then determines an estimated transmitter beamforming unitary matrix (V) based upon the channel response and a known receiver beamforming unitary matrix (U) (step 704). The channel response (H), estimated transmitter beamforming unitary matrix (V), and the known receiver beamforming unitary matrix (U) are related by the equation **H=UDV***, where, D is a diagonal matrix. Singular Value Decomposition (SVD) operations may be employed to produce the estimated transmitter beamforming unitary matrix (V) according to this equation.
>
> According to the embodiment of FIG. 7, the receiving wireless device **produces the estimated transmitter beamforming unitary matrix (V) in Cartesian coordinates** and then converts the estimated transmitter beamforming unitary matrix (V) to polar coordinates (step 706).

Id. at 13:44–58.

> The receiving wireless device then decomposes the channel response (H) based upon the receiver beamforming unitary matrix (U) to produce an estimated transmitter beamforming unitary matrix (V) (step 804).

Id. at 14:27–30.

200. As cited above, the specification discloses an algorithm for step 704 in the embodiment of Figure 7. No algorithm is disclosed to perform step 804 in the embodiment of Figure 8 anywhere in the specification.

201. Accordingly, it is my opinion that a POSITA would understand that the corresponding structure for the "determine an estimated transmitter beamforming unitary matrix (V) based upon the channel response and a receiver beamforming

unitary matrix (U)" function is thus, "a processing device programmed with operational instructions to produce an estimated transmitter beamforming unitary matrix (V) according to the equation H=UDV* as described at 13:44–58, by employing Singular Value Decomposition (SVD) operations to produce the estimated transmitter beamforming unitary matrix (V) in Cartesian coordinates."

(4) decompose the estimated transmitter beamforming unitary matrix (V) to produce the transmitter beamforming information;

202. The specification discloses sufficient structure for the "decompose . . ." function in the form of an algorithm that defines the structure of the claimed baseband processing module and makes the bounds of the claims understandable to a POSITA, as explained below.

203. The specification discloses sufficient structure for performing the "decompose . . ." function.

204. The specification discloses the "decompose the estimated transmitter beamforming unitary matrix (V) . . ." function in the context of steps 708 and 806 of the embodiments of Figures 7 and 8:

> According to one embodiment of this operation, the decomposition operations of step 708 employ a Givens Rotation operation. The Givens Rotation relies upon the observation that, with the condition of V*V=VV*=I, some of angles of the Givens Rotation are redundant. With a decomposed matrix form for the estimated transmitter beamforming matrix (V), the set of angles fed back to the transmitting wireless device are reduced.

Id. at 13:63–14:3.

> With the estimated transmitter beamforming unitary matrix (V) determined, the receiving wireless device then decomposes the estimated transmitter beamforming unitary matrix (V) using a Givens Rotation to produce the transmitter beamforming

> information (step 806). **The products of this Givens Rotation are the transmitter beamforming information**.

Id. at 14:30–37.

205. In Figure 7, step 708 states "Decompose the **polar coordinate estimate** of beamforming matrix (V) to reduce a number of feedback components (transmitter beamforming information)." *Id*. at Fig. 7.

206. The specification discloses examples of the angles produced by the Givens Rotation. For example, two angles (ψ, Φ) are produced by the Givens Rotation for a 2x2 estimated transmitter beamforming matrix (V). *Id*. at 14:48–15:8; *see also id*. at 15:38–40 (identifying six angles for a 3x3 estimated transmitter beamforming matrix (V); *id*. at 15:49–51 (identifying twelve angles for a 4x4 estimated transmitter beamforming matrix (V).

207. Accordingly, it is my opinion that a POSITA would understand that the corresponding structure for the "decompose the estimated transmitter beamforming unitary matrix (V) to produce the transmitter beamforming information" function is thus, "a processing device programmed with operational instructions to decompose the polar coordinate estimated transmitter beamforming unitary matrix (V) to produce the transmitter beamforming information (i.e., factor the estimated transmitter beamforming unitary matrix (V) to produce a reduced set of angles) by using a Givens Rotation operation as described at 14:48–15:8, 15:18–33, 15:38–40, and 15:49–51."

(5) form a baseband signal employed by the plurality of RF components to wirelessly send the transmitter beamforming information to the transmitting wireless device

208. The specification fails to disclose sufficient structure for performing the "form . . ." function.

209. In the context of steps 710 and 808 of the embodiments of Figures 7 and 8, the specification states:

> Operation continues with the receiving wireless device wirelessly sending the transmitter beamforming information to the transmitting wireless device (step 710). This operation occurs with the receiving wireless device shifting to a transmit mode and sending the information back to the transmitting wireless device.

Id. at 14:4–10.

> Operation continues with the receiving wireless device wirelessly sending the transmitter beamforming information to the transmitting wireless device (step 808). This operation occurs with the receiving wireless device shifting to a transmit mode and sending the transmitter beamforming information to the transmitting wireless device.

Id. at 14:38–43.

210. No algorithm is disclosed by these passages or anyone else in the specification to perform the "form a baseband signal . . ." function. BNR states that structure is found in the specification at "Figs. 2-5, Col. 5:49–6:12, 6:37–7:20; 7:51–9:30; 9:31–13:35; 13:54–15:67," but provides no further details. It is not apparent from these citations what BNR is identifying as structure. Based on my review, no algorithm for performing the "form a baseband signal . . ." function is disclosed by the information BNR cited. Accordingly, it is my opinion that a POSITA would understand that the baseband processing module term is indefinite for lack of structure to perform the "form a baseband signal employed by the plurality of RF components to wirelessly send the transmitter beamforming information to the transmitting wireless device" function.

c. "the baseband processing module is operable to: produce the estimated transmitter beamforming unitary matrix (V) in

Cartesian coordinates; and convert the estimated transmitter beamforming unitary matrix (V) to polar coordinates"

'862 Patent Claim Term	**BNR's Proposed Construction**	**Defendants' Proposed Construction**
"the baseband processing module is operable to: produce the estimated transmitter beamforming unitary matrix (V) in Cartesian coordinates; and convert the estimated transmitter beamforming unitary matrix (V) to polar coordinates"	Not a 112 ¶ 6 claim element – "baseband processing module" is not a nonce word. Instead, a baseband processing module is itself sufficient structure. A POSA would know this is a baseband processor implemented in ASIC, FGPA, logic circuits, or the like in RF communication hardware. In the alternative, to the extent the Court determines that this claim is governed by 112 ¶ 6, BNR proposes the following Function and Structure, and disagrees that the term is indefinite for lack of corresponding structure: <u>Function</u>: "a baseband processing module operable to . . . produce the estimated transmitter beamforming unitary matrix (V) in Cartesian coordinates; and convert the estimated	This is a 112 ¶ 6 claim element. <u>Function</u>: "a baseband processing module operable to . . . produce the estimated transmitter beamforming unitary matrix (V) in Cartesian coordinates; and convert the estimated transmitter beamforming

’862 Patent Claim Term	BNR’s Proposed Construction	Defendants’ Proposed Construction
	transmitter beamforming unitary matrix (V) to polar coordinates” Structure: Corresponding structure for the alleged function exists in at least the following portions of the patent specification, or their equivalents: Figs. 2-5, Col. 5:49–6:12, 6:37–7:20; 7:51–9:30; 9:31–13:35; 13:54–15:67.	unitary matrix (V) to polar coordinates” Structure: Indefinite for lack of corresponding structure in the patent specification.

Joint Claim Construction Worksheet, Appendix A at 18–21.

211. The term “the baseband processing module is operable to: produce the estimated transmitter beamforming unitary matrix (V) in Cartesian coordinates; and convert the estimated transmitter beamforming unitary matrix (V) to polar coordinates” is used in claim 10.

212. It is my opinion that, at the time of the filing of the ’862 Patent, a POSITA would understand this term to be a means-plus-function term that is indefinite for lack of corresponding structure to perform the recited function, as Defendants propose. My opinion is supported by the disclosures in the ’862 Patent as I explain in the following paragraphs.

213. As I explained above, the “baseband processing module . . .” term of claim 9 is a means-plus-function term because the term does not identify sufficiently definite structure. Claim 10 includes further limitations of that “baseband processing

module . . .” term, and similarly does not identify sufficiently definite structure. Claim 10 recites two functions—“produce” and “convert.”

214. A POSITA would understand that the claim limitation includes a general purpose computer (e.g., microprocessor). But, that is not sufficient structure to perform the claimed functions. An off-the-shelf general purpose computer is not capable of performing the functions of the claim without special programming. Special programming is necessary for a general purpose computer to perform the “produce” and “convert” functions.

215. As such, I understand that the “baseband processing module” term must be construed as a means-plus-function term. BNR and Defendants agree that the functions recited by this term are: “a baseband processing module operable to . . . produce the estimated transmitter beamforming unitary matrix (V) in Cartesian coordinates; and convert the estimated transmitter beamforming unitary matrix (V) to polar coordinates.” Based on my review of the language of claim 10, I also agree that a POSITA would understand this to be the recited function.

216. To disclose sufficient structure for a general purpose computer, I understand that the specification must disclose the algorithm for performing the claimed functions. Following is my analysis of (1) whether the specification discloses an algorithm, and (2) if so, whether that algorithm defines the structure of the claimed baseband processing module and makes the bounds of the claims understandable to a POSITA.

(1) produce the estimated transmitter beamforming unitary matrix (V) in Cartesian coordinates

217. The specification discloses sufficient structure for the “produce . . .” function in the form of an algorithm that defines the structure of the claimed

baseband processing module and makes the bounds of the claims understandable to a POSITA.

218. As explained above for the "determine an estimated transmitter beamforming unitary matrix (V) based upon the channel response and a receiver beamforming unitary matrix (U)" function in claim 9, the specification discloses an algorithm to "produce the estimated transmitter beamforming unitary matrix (V) in Cartesian coordinates" function.

219. Accordingly, it is my opinion that a POSITA would understand that the corresponding structure for the "produce the estimated transmitter beamforming unitary matrix (V) in Cartesian coordinates" function is thus, "a processing device programmed with operational instructions to produce an estimated transmitter beamforming unitary matrix (V) according to the equation H=UDV* as described at 13:44–58, by employing Singular Value Decomposition (SVD) operations to produce the estimated transmitter beamforming unitary matrix (V) in Cartesian coordinates."

(2) convert the estimated transmitter beamforming unitary matrix (V) to polar coordinates

220. In the context of steps 706 of the embodiment of Figures 7, the specification states:

> According to the embodiment of FIG. 7, the receiving wireless device produces the estimated transmitter beamforming unitary matrix (V) in Cartesian coordinates and then converts the estimated transmitter beamforming unitary matrix (V) to polar coordinates (step 706).

Id. at 13:54–58.

221. No algorithm is disclosed by this passage or anywhere else in the specification to perform the "convert the estimated transmitter beamforming unitary

matrix (V) to polar coordinates" function. BNR states that structure is found in the specification at "Figs. 2-5, Col. 5:49–6:12, 6:37–7:20; 7:51–9:30; 9:31–13:35; 13:54–15:67," but provides no further details. It is not apparent from these citations what BNR is identifying as structure. Based on my review, no algorithm for performing the "convert the estimated transmitter beamforming unitary matrix (V) to polar coordinates" function is disclosed by the information BNR cited. Accordingly, it is my opinion that a POSITA would understand that the baseband processing module term is indefinite for lack of structure to perform the "convert the estimated transmitter beamforming unitary matrix (V) to polar coordinates" function.

Exhibit A

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Academy Building Room 218A
St. Louis, MO 63130

Education

Year	College or University	Degree
1987	The University of Michigan	Ph.D. in Electrical Engineering
1984	The University of Michigan	M.S. in Electrical Engineering
1982	The University of Michigan	B.S. in Electrical Engineering

Professional Experience

From: 1990
To: Present
Organization: Washington University, St. Louis

Summary:

2015 -	Senior Professor - Department of Electrical Systems Engineering
2011 – 2014	Chair – Undergraduate Curriculum, Department of Electrical and Systems Engineering
2000 – 2002	Chair – Graduate Curriculum, Department of Electrical and Systems Engineering
2002 - 2014	Associate Professor - Department of Electrical and Systems Engineering
1997 - 2008	On leave from full-time duty at Washington University – as Presidents of MinMax Technologies and Erlang Technology.)
1996 - 2002	Associate Professor - Department of Electrical Engineering
1996	Promoted with Tenure

1990 - 1996 Assistant Professor - Department of Electrical Engineering

Teaching Experience

- "Transmission System and Multiplexing," Washington University, ESE 571
- "Electrical Laboratory I," Washington University, EE 250.
- "Communication Theory," Washington University, ESE 471.
- "Reliability and Quality Control," Washington University, ESE 405/505
- "Signaling and Control of Communications Networks," Washington University, ESE 572.
- "Introduction to Electronic Circuits," Washington University, ESE232
- "Queueing Systems and Discrete Stochastic Processes," Washington University, EE 536 / CS 567.
- "Digital Computer," Washington University, EE 260M / CS 260.
- "Data Networks," Washington University, EE 530.
- "Electrical Circuit Analysis," Washington University, ESE 230.
- "Computer/Communications System Analysis I," Washington University, EE 557/ CS 557.
- "Computer/Communications System Analysis II," Washington University, EE558 / CS 558.
- "Digital Systems Laboratory," Washington University, EE 455 / CS 455.

From: 1999
To: 2008
Organization: Erlang Technology, Inc., St. Louis, Missouri
Title: Founder and President
Summary: Up to 70 employees, $40M in total capital raised from 5 VCs and 3 Corporations
Received "Product of Year" Award from Analog Zone Magazine in 2004

From: 1997
To: 1999
Organization: MinMax Technologies, Inc., St. Louis, Missouri
Title: Founder and President
Summary: Fabless semiconductor company, designing high performance switching ASICs

From: September 1987
To: August 1990
Organization: Bellcore, New Jersey
Title: Member of Technical Staff
Summary: Member of New Network Architecture Development Group

From: 1983
To: 1987

Organization: Department of Electrical Engineering, The University of Michigan
Title: Graduate Instructor
Summary: Instructor for senior level Electrical Engineering Laboratory Class. Received a Best "Best Graduate Instructor Award" from the Department of Electrical Engineering

Professional Affiliations, Achievements & Awards

- Technical Program Committee, COMCAS 2019, Tel Aviv, November 2019.
- Technical Program Committee, COMCAS 2017, Tel Aviv, November 2017.
- Technical Program Committee, COMCAS 2015, Tel Aviv, October 2015.
- Past-Chair, Saint Louis Section of the Institute of Electrical and Electronics Engineers (IEEE), 2015.
- Member of Executive Committee, Saint Louis Section of the IEEE, 2010-2015.
- Chair, Saint Louis Section of the IEEE, 2014.
- Technical Program Committee, COMCAS 2013, Tel Aviv, October 2013.
- Vice Chair, Saint Louis Section of the IEEE, 2013
- Treasurer, Saint Louis Section of the IEEE, 2012.
- The Best Paper Award at MOBILITY 2011, October 2011, Barcelona, Spain.
- Counselor, Student Chapter of the Year, the Institute of Electrical and Electronics Engineers, 2011.
- Award of Appreciation, Saint Louis Section of the Institute of Electrical and Electronics. Engineers, 2011, for contribution to various activities of the Saint Louis Section the Institute of Electrical and Electronics Engineers.
- Secretary, Saint Louis Section of the IEEE, 2010.
- Counselor, Student Chapter of the Year, the Institute of Electrical and Electronics Engineers, 2010.
- Wall Street Journal Businessmen of Year, 2003.
- American Men and Women of Science, listed in 1997.
- Outstanding Achievement Award, Bellcore, 1990.
- 18th ISATA Award of Technical Excellence, the best paper award at ISATA 1988.
- Rockwell Fellow, Rockwell International, 1985, 1986.
- Outstanding Graduate Student Award, the University of Michigan, 1985.
- Outstanding Teaching Award, the University of Michigan, 1984, 1986.
- Member of Honor's College, the University of Michigan, 1979, 1980.
- Honor's Convocation, the University of Michigan, 1979.
- Outstanding Freshman Award, the University of Michigan, 1979.

- Woodhaven Rotary Club Scholarship, Woodhaven Rotary Club, 1978.
- Second Place Winner, the State of Michigan Mathematics Prize Competition, 1977.
- International Program Committee, *IASTED International Conference on Communications, Internet and Information Technology (CIIT 2005*), Cambridge, Massachusetts from October 31-November 2, 2005.
- International Program Committee, *IASTED International Conference on Communications 2003*, Scottsdale, Arizona, 2003.
- International Program Committee, *Wireless and Optical Communications 2003*, Banff, Canada, 2003.
- International Program Committee, Session Chair, *Wireless and Optical Communications 2002*, Banff, Canada, 2002.
- Invited participant, *NSF Workshop on Enhancing International Cooperation in CS/CE Research and Education*, Portland, 1997.
- Session Chair, *the 1993 Conference on Information Sciences and Systems*, Baltimore, March 1997.
- Member, Board of Editors, *Journal of Network and Systems Management*, 1996-1998.
- Program Committee, *International Symposium on Integrated Network Management*, San Diego, 1997.
- Guest Editor, *Journal of Network and Systems Management*, *Special Issue on Routing in Broadband Networks*, December 1995 and June 1996.
- Invited participant, *ARPA Workshop on Survivability of Large Scale Systems*, Washington D.C., 1996.
- Special Event Organizer, *International Symposium on Integrated Network Management*, Santa Barbara, 1995.
- Organizing Committee, *International Symposium on Integrated Network Management*, Santa Barbara, 1995.
- Local Arrangements Chair, *IEEE Information Theory Workshop on Information Theory Multiple Access and Queueing*, St. Louis, 1995.
- Chair, *Communications Chapter, St. Louis Section of the IEEE*, 1995.
- Participant, *IEEE Information Theory Workshop on Information Theory, Multiple Access and Queueing*, St. Louis, 1995.
- Participant, *ARPA/AFOSR Non-Linear Optics and Communication Workshop*, Denver, 1994.
- Participant, *CNRI Giga Bit Network Workshop*, Washington D.C., 1993.
- Participant, *IFIP/IEEE International Workshop on Distributed Systems*, New Jersey, 1993.
- Program Committee, *International Conference on Computer Communications and Networks*, San Diego, 1992.
- Session Chair, *ISMM International Conference*, New Orleans, 1990.
- Senior Member, *IEEE*.
- Member, *IEEE Committee on Network Operations and Management*.
- Member, *IEEE Committee on Computer Communications*.

- Registered Specialist, *Hong Kong Research Grant Council*.
- Reviewer, *IEEE Transactions on Communications*.
- Reviewer, *IEEE Transactions on Networking*.
- Reviewer, *IEEE Journal on Selected Areas in Communications*.
- Reviewer, *Journal of Network and Systems Management*.
- Reviewer, *Telecommunication Systems*.
- Reviewer, Computers and Electrical Engineering.
- Reviewer, *ETRI Journal*.
- Reviewer, *IEEE Transactions on Automatic Control*.
- Reviewer, *IEEE Communications*.
- Book Reviewer, *Prentice Hall*.
- Book Reviewer, *Morgan Kaufmann Publishers, Inc.*
- Book Reviewer, *Irwin Publishing Co.*

University Activities:

- Undergraduate Studies Committee, School of Engineering and Applied Science (2012 – Present)
- Faculty Advisor for IEEE Student Chapter (2009 – Present)
- Ambassador for McDonnell International Scholar Academy (2007 – 2013)
- Web Development Committee (2006 – 2008)
- University Judicial Board (1998 - 2000)
- Resource Generation Committee (1994 - 1995)
- Top 20 Committee (1992 - 1995)
- Telecommunications Committee, Chair (1991 - 1997)
- Library Planning Committee (1991 - 1992)
- Computer Engineering Committee (1990 - 1996)
- Communications Curriculum Committee (1990 - 1992)
- Resources Committee (1990 - 1992)

Patents

Patent No.	Date	Title
10,284,476	05/07/19	Hierarchical Pattern Matching Devices and Methods
7,110,411	09/19/06	Method of and Apparatus for WFQ Scheduling Using a Plurality of Scheduling Queues to Provide Fairness, High Scalability, and Low Computational Complexity

7,106,738	09/12/06	Method of and Apparatus for High Speed Packet Switching Using Train Packet Queuing and Providing High Scalability
6,859,455	02/22/05	Method of and Apparatus for Building and Using Multi-Dimensional Index Trees for Multi-Dimensional Data Objects
6,614,789	09/02/03	Method of and Apparatus for Matching Strings of Different Lengths
6,359,885	3/19/02	Multi-Channel Packet Switching Apparatus Having Traffic Flow Controlling and Checking Functions
6,128,292	10/03/00	Packet Switching Apparatus with Multi-Channel and Multi-Cast Switching Functions and Packet Switching System Using the Same
5,788,161	12/13/98	Network Designer for Communication Networks
5,526,352	06/11/95	Integrable Low Complexity Multi-Channel Switch
5,440,549	08/08/95	Nonblocking Multi-Channel Switching with Multicasting Capability

Publications

- Yu, Qixiang, Luo, Z, and Min, P.S., "Intrusion Detection in Wireless Sensor Networks for Destructive Intruders." Proceedings of the APSIPA 2015 conference. December 16-19, 2015.
- Hung, C.P., and Min, P.S., "Simple Web Application Framework." Submitted for publication in the IEEE Transactions on Cloud Computing.
- Luo, Z., and Min, P.S., "Parallel Implementation of Energy-Based Target Localization Methods in Wireless Sensor Networks." Proceeding of the 2014 IEEE SOUTHEASTCON.
- Yu, Q., Luo, Z., and Min, P.S., "Intrusion Detection in Wireless Sensor Networks for Destructive Intruder." Proceeding of 2014 International Conference on Smart Computing (SMARTCOMP 2014).
- Luo, Z., and Min, P.S., "Survey of Target Localization Methods in Wireless Sensor Networks," 19th IEEE International Conference on Networks (ICON 2013), Singapore, December 11-13, 2013.
- Hung, C.P., and Min, P.S., "Deriving and Visualizing the Lower Bounds of Information Gain for Prefetch Systems," 19th IEEE International Conference On Networks (ICON 2013), Singapore, December 11-13, 2013.
- Hung, C.P., and Min, P.S., "Access LUT without CAM - Improved Pearson Hashing for Collision Reduction," 19th IEEE International Conference On Networks (ICON 2013), Singapore, December 11-13, 2013.
- Luo, Z and Min, P.S., "Target Localization in Wireless Sensor Networks for Industrial Control with Selected Sensors." International Journal of Distributed Sensor Networks, Volume 2013 (2013), Article ID 304631.
- Hung, C.P., and Min, P.S. "Performance Evaluation of Distributed Mobile Application Virtualization Services," International Journal on Advances in Internet Technology, Vol. 5, no. 3&4, 2012, pp. 65-83.
- Hung, C.P. and Min, P.S., "Performance evaluation of distributed application virtualization services using the UMTS mobility model," MOBILITY 2011 The First International Conference on Mobile Services, Resources, and Users, 23-29 Oct. 2011.

- Hung, C.P. and Min, P.S., "Service Area Optimization For Application Virtualization Using UMTS Mobility Model," International Conference on Internet Computing, pp. 128-134, Las Vegas, July 18-21, 2011.
- Hung, C.P. and Min, P.S., "Application Virtualization Using UMTS Mobility Model," ICOMP'11, September, 2011.
- Hung, C.P. and Min, P.S., "Infrastructure Arrangement for Application Virtualization Service," the 9th International Information and Telecommunication Technologies Symposium, Vol.1, pp. 78-85, Rio de Janeiro, December 2010.
- Hung, C.P. and Min, P.S., "Probabilistic Approach to Network-Based Virtual Computing," the 9th International Information and Telecommunication Technologies Symposium, Vol.1, pp. 117-124, Rio de Janeiro, December 2010.
- Shiravi, A. and Min, P. S., "On the Latency Bound of Proportional Nested-DRR with Credit Adjusting," *2007 Workshop on High Performance Switching and Routing HPSR 2007*, July 2007.
- Shiravi, A. and Min, P. S., "LOOFA-PB: A Modified LOOFA Scheduler for Variable-Length Packet Switching." *2007 IEEE International Conference on Communications (ICC 2007),* Glasgow, June 2007.
- Shiravi, A., Kim, Y. G., and Min, P. S., "Congestion Prediction of Self-Similar Network through Parameter Estimation," *Proceedings of 2006 IEEE/IFIP Network Operations & Management Symposium*, April 2006, Vancouver.
- Shiravi, A., Kim, Y. G., and Min, P. S., "Traffic Dispatching Algorithm in Three-Stage Switch," *Proceedings of 5th International Conference on Networking*, April 2006, Mauritius.
- Shiravi, A., Kim, Y. G., and Min, P. S., "Proportional Nested Deficit Round Robin with Credit Adjusting," *Proceedings of 2nd Int'l Conf. on Quality of Service in Heterogeneous Wired/Wireless Networks (QShine 2005)*, Orlando, August 2005.
- Shiravi, A., Kim, Y. G., and Min, P. S., "Proportional Nested Deficit Round Robin: Improving the Latency of Packet Scheduler with an O(1) Complexity," *Proceedings of International Workshop on Advanced Architectures and Algorithms for Internet Delivery and Applications (AAA-IDEA 2005),* Orlando, June 2005
- Kim, Y. G., Shiravi, A., and Min, P. S., "Prediction-Based Routing through Least Cost Delay Constraint," *Proceedings of IEEE IPDPS 2004*, Santa Fe, April 2004.
- Kim, Y. G. and Min, P. S., "On the Prediction of Average Queuing Delay with Self-Similar Traffic," *Proceedings of IEEE GLOBECOM 2003*, San Francisco, December 2003.
- Hu, C., Saidi, H., Yan, P. Y., and Min, P.S., "A Protocol Independent Policer And Shaper Using Virtual Scheduling Algorithm," *Proceedings of ICCCAS 2002*.
- Hu, C., Saidi, H., and Min, P.S., "DB_WFQ: An Efficient Fair Queueing Using Binary Counter," *Proceeding of Coins 2002*.
- Yoon, U. and Min, P.S., "Performance Analysis of Radio Link Control Mechanism in W-CDMA System", IEEE VTC'01 Fall, October 2001, New Jersey

- Akl, B., Hegde, M.V., Naraghi-Pour, M., and Min, P.S., "Multi-Cell CDMA Network Design," *IEEE Transaction on Vehicular Technology*, Volume 50, No. 3, pp. 711-722, May 2001.
- Yoon, U., Park, S., Min, P.S., "Performance Analysis of Multiple Rejects ARQ at RLC (Radio Link Control) for Packet Data Service in W-CDMA System," *IEEE Globecom*, November 2000, San Francisco.
- Yoon, U., Park, S., Min, P.S., "Performance Analysis of Multiple Rejects ARQ for RLC (Radio Link Control) in the Third Generation Wireless Communication," *WCNC*, September 2000, Chicago.
- Yoon, U., Park, S., Min, P.S., "Network Architecture and Wireless Data Service Protocol based on Mobile IP toward the Third Generation Wireless Communication," *3G Wireless*, June 2000, San Francisco, pp. 211-215
- R.G. Akl, M.V. Hegde, M. Naraghi-Pour, P.S. Min, "Multi-Cell CDMA Network Design," *IEEE International Conference on Communications*, June 2000.
- R.G. Akl, M.V. Hegde, M. Naraghi-Pour, P.S. Min, "CDMA Network Design to Meet Non-uniform User Demand," *International Teletraffic Congress*, March 2000.
- R.G. Akl, M.V. Hegde, M. Naraghi-Pour, P.S. Min, "CDMA Network Design," *IEEE Transactions on Vehicular Technology*.
- R.G. Akl, M.V. Hegde, M. Naraghi-Pour, P.S. Min, "Cell Placement in a CDMA Network," *IEEE Wireless Communications and Networking Conference*, September 1999, Volume 2, pp. 903-907.
- R.G. Akl, M.V. Hegde, P.S. Min, "Effects of Call Arrival Rate and Mobility on Network Throughput in Multi-Cell CDMA," *IEEE International Conference on Communications*, June 1999, Volume 3, pp. 1763-1767.
- Hegde, M.V., Schmid, O.A., Saidi, H., and Min, P.S., "Real-Time Adaptive Bandwidth Allocation for High-Speed ATM Switches," accepted, *International Conference on Communications*, June 1999.
- Akl, B.G., Hegde, M.V., and Min, P.S., "Effects of Mobility on Network Throughput in Multicell CDMA Networks," accepted, *International Conference on Communications*, June 1999.
- Akl, B.G., Hegde, M.V., Min, P.S., and Naraghi-Pour, M., "Flexible Allocation of Capacity in Multi-Cell CDMA Networks," accepted, *Vehicular Technology Conference*, June 1999.
- R.G. Akl, M.V. Hegde, M. Naraghi-Pour, P.S. Min, "Flexible Allocation of Capacity in Multi-Cell CDMA Networks," *IEEE Vehicular Technology Conference*, May 1999, Volume 2, pp. 1643-1647.
- Oh, M.S., and Min, P.S., "Reliability Analysis for One-Turn and Deflection Crossbar Architectures and Distributed Fault Recovery Scheme," *Proceedings of GLOBECOM 97*, Phoenix, November 1997.

- Kim, K.B., Yan, P.Y., Kim, K.S., Schmid, O., and Min, P.S., "A Growable ATM Switch with Embedded Multi-Channel Multicasting Property," *Proceedings of GLOBECOM 97*, pp. 222-226, Phoenix, November 1997.
- Kim, K.B., Yan, P.Y., Kim, K.S., Schmid, O., and Min, P.S., "MASCON: A Single IC Solution to ATM Multi-Channel Switching with Embedded Multicasting," *Proceedings of ISS 97*, pp. 451-458, Toronto, September 1997.
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- Yan, P.Y., Kim, K.S., Min, P.S., and Hegde, M.V., "Multi-Channel Deflection Crossbar (MCDC): A VLSI Optimized Architecture for Multi-Channel ATM Switching," *Proceedings of IEEE INFOCOM 97*, Kobe, Japan, April 1997.
- Maunder, A., Rayes, A., and Min, P.S., "Analysis and Rate Controlling Link: Leaky Bucket with Finite Servers," *Proceedings of the 1997 Conference on Information Sciences and Systems*, Baltimore, March 1997.
- Shin, S.W., Min, P.S., and Kim, J.H., "Real Time Traffic Management System at Korean Mobile Telecom," *Proceedings of 19th Annual Pacific Telecommunications Conference*, pp. 113-121, Honolulu, Hawaii, January 1997.
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- Rayes, A. and Min, P.S., "Capacity Expansion of Least Busy Alternate Routing with Shadow Price," *Proceedings of GLOBECOM 95*, Singapore, November 1995.
- Min, P.S., Hegde, M.V., Chandra, A., and Maunder, A., "Throughput and Delay for Copy Networks with Internal Buffers," *Proceedings of the 33rd Annual Allerton Conference*, October 1995.
- Min, P.S., Hegde, M.V., Saidi, H., and Chandra, A., "Fanout Splitting in Nonblocking Copy Networks with Shared Buffering," *Proceedings of the 33rd Annual Allerton Conference*, October 1995.
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- Min, P.S., Hegde, M.V., Saidi, H., and Chandra, A., "Multi-Channel Copy Networks: Architecture, Performance Model, Fairness, and Cell Sequencing," *Proceedings of IEEE INFOCOM 95*, pp. 931-938, Boston, April 1995.
- Min, P.S., Hegde, M.V., and Chandra, A., "Analysis of Packet Movements in Internally Buffered Copy Networks," *Third ORSA Telecommunications Conference*, p. 141, Boca Raton, Florida, March 1995.
- Maunder, A. and Min, P.S., "Routing for Multi-Rate Traffic with Multiple Qualities of Service," *Proceedings of the Third International Conference on Computer Communications and Networks*, pp. 104-108, San Francisco, September 1994.
- Saidi, H. and Min, P.S., "Performance Benefits of Multi-Channel Switching," *Proceedings of the 32nd Annual Allerton Conference*, pp. 583-592, September 1994.
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- Min, P.S., Hegde, M.V., Saidi, H., and Chandra, A., "Shared Buffering in Nonblocking Copy Networks," *Proceedings of the 1994 IEEE International Symposium on Information Theory*, Norway, p. 406, June 1994.
- Min, P.S., Hegde, M.V., and Rayes, A., "Real Time Traffic Estimation in Circuit-Switched Networks," *Proceedings of the 14th International Teletraffic Congress*, France, pp. 1175-1184, June 1994.
- Hegde, M.V., Min, P.S., and Rayes, A., "State Dependent Routing: Traffic Dynamics and Performance Benefits," *Journal of Network and Systems Management*, Volume 2, No. 2, pp. 125-149, June 1994.
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- Saidi, H., Min, P.S., and Hegde, M.V., "Nonblocking Multi-Channel Switching in ATM Networks," *Proceedings of the 1994 International Conference on Communications*, New Orleans, pp. 701-705, May 1994.
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- Rayes, A. and Min, P.S., "Capacity Expansion in State Dependent Routing Schemes," *Proceedings of the 1994 Conference on Information Sciences and Systems*, Princeton, pp. 237-241, March 1994.
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- Saidi, H., Min, P.S., and Hegde, M.V., "Non-Blocking Multi-Channel Switching." Invited paper. *Proceedings of the 31st Annual Allerton Conference*, pp. 335-344, September 1993.
- Min, P.S., Hegde, M.V., and Rayes, A., "Model Based Estimation of Exogenous Traffic," *Proceedings of the 1993 Conference on Information Sciences and Systems*, Baltimore, pp. 126-131, March 1993.
- Hegde, M.V., Min, P.S., and Rayes, A., "Performance Analysis of State Dependent Routing," *Proceedings of the 1993 Conference on Information Sciences and Systems*, pp. 695-700, Baltimore, March 1993.
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- Hegde, M.V. and Min, P.S., "Performance Analysis of State Dependent Routing." Invited paper. *Second ORSA Telecommunications Conference*, Boca Raton, Florida, February 1992.
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- Min, P.S. and Hegde, M.V., "End-to-End Planning Models for Optimal Evolution of Telecommunications Network," *Proceedings of IEEE INFOCOM 90*, San Francisco, pp. 200-206, June 1990.
- Min, P.S., "Validation of Controller Inputs in Electronically Controlled Engines." Invited paper. *Proceedings of the 1990 American Control Conference*, pp.2887-2890, San Diego, May 1990.
- Min, P.S. and Youn, C., "Generic Equipment Models (GEM) for Consistent Planning of Telecommunications Networks," *Proceedings of the 1990 ISMM International Conference*, New Orleans, pp. 190-194, March 1990.
- Min, P.S., "Robust Application of Beard-Jones Detection Filter," *Advances in Computing and Control*, Springer-Verlag, Volume 130, pp. 162-173, 1989.
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- Min, P.S., "Robust Application of Beard-Jones Detection Filter," *Proceedings of the 1989 American Control Conference*, Pittsburgh, pp. 859-864, June 1989.
- Rizzoni, G. and Min, P.S., "Real Time Detection Filters for the On-board Diagnosis of Incipient Failures," *Proceedings of the 1989 International Symposium on Allied Technology and Automation*, pp. 1445-1466, Paper No. 89131, Florence, Italy, June 1989.
- Min, P.S., "Diagnosis of On-Board Sensors in Internal Combustion (IC) Engines," *Proceedings of the 1989 American Control Conference*, Pittsburgh, pp. 1065-1070, June 1989.
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Testimony Provided or Expected to Provide as Expert Witness

Matter: Patent Infringement for Internet Switching
Law Firm: Maynard Cooper

Case Name: Parity Networks, LLC v. Juniper Networks, Inc., Case No. 6:17-CV-00495-RWS-KNM (U.S.D.C.E.D. Tx.)
Testifying Expert for Juniper.
Retained in April 2018.

Matter: Inter Parte Rexamination for Covered Business Method
Law Firm: Reed Smith LLP
Case Name: NASDAQ v. Miami International
Expert for Miami International.
Retained in February 2018.
(Expert declarations submitted, and deposed.)

Matter: Patent Infringement for Mobile Devices
Law Firm: Quinn Emanuel
Case Name: Qualcomm v. Apple, Case No. 3:17-cv-00108-GPC-MDD (U.S.D.C.S.D. Cal.)
Testifying Expert for Qualcomm.
Completed in April 2019.
(Expert reports submitted, and deposed.)

Matter: Patent Infringement for Communication Devices
Law Firm: Venable
Case Name: Sycamore IP Holdings LLC v. Verizon Communications Inc, Case No. 2:16-cv-591-JRG-RSP (U.S.D.C. E.D. Texas)
Testifying Expert for Verizon and Level 3.
Completed in September 2017.
(Expert reports submitted, and deposed.)

Matter: Patent Infringement for Mobile Devices
Law Firm: Alston Bird
Case Name: Huawei Technologies Co. Ltd. V. Nokia Solutions and Networks, Case No. 2:16-cv-0056-JRG-RSP (U.S.D.C. E.D. Texas)
Testifying Expert for Nokia.
Completed in December 2017.
(Expert reports submitted.)

Matter: Patent Infringement for Mobile Devices
Law Firm: Quinn Emanuel
Case Name: Huawei Technologies Co. Ltd. V. Samsung Electronics C. Ltd, Case No. 3:16-cv-02787 (U.S.D.C. N.D. Cal)
Testifying Expert for Samsung.
Completed in March 2019.
(Expert reports submitted, and deposed.)

Matter: Arbitration for Licensing
Law Firm: Alston Bird

Case Name: Nokia v. LG Electronics, International Chamber of Commerce Arb. No. 21326
Testifying Expert for Nokia.
Completed in October 2016.
(Expert reports submitted.)

Matter: Patent Infringement for Mobile Devices
Law Firm: Ropes and Gray
Case Name: Godo Kaisha IP Bridge 1 v. TCL Communication Technology Holdings, Case No. 15-634-SLR-SRF (U.S.D.C.S.D. Delaware.)
Testifying Expert for IP Bridge.
Completed in October 2018.
(Expert reports submitted, and deposed.)

Matter: Patent Infringement for Mobile Devices
Law Firm: Paul Hastings
Case Name: Odyssey Wireless, Inc,. v. Samsung Electronics Co., Ltd., et al, Case No. 3:15-cv-1738-H-RBB (U.S.D.C.S.D. Cal.)
Testifying Expert for Samsung.
Completed in October 2016.
(Expert reports submitted.)

Matter: Patent Infringement for Mobile Devices
Law Firm: Greenberg Traurig
Case Name: Mobile Telecommunications Technologies LLC v. Amazon.com, Inc., 2:13-cv-883-JRG-RSP (U.S.D.C. E.D. Texas)
Testifying Expert for Amazon.
Completed in April 2015.
(Expert reports submitted, and deposed.)

Matter: Patent Infringement for Mobile Devices
Law Firm: Mayer Brown
Case Name: Mobile Telecommunications Technologies LLC v. LG Electronics Mobilecomm U.S.A., Inc., 2:13-cv-947-JRG-RSP (U.S.D.C. E.D. Texas)
Testifying Expert for LG Electronics Mobilecomm.
Completed in February 2016.
(Expert reports submitted, and deposed.)

Matter: Patent Infringement for Semiconductor Devices
Law Firm: Mayer Brown
Case Name: Inter Parte Reexamination for U.S. Patent Nos. 6,895,520 and 6,899,332
Expert for LG Electronics.
Completed in February 2016.

(Expert declaration submitted, and deposed.)

Matter: Patent Infringement in Vehicular Electronics
Law Firm: Gardner, Linn, Burkhart & Flory, L.L.P
Case Name: *Magna Electronics Inc. v. TRW Automotive Holdings Corp. et al.*, Civil Action No. 1:12-cv-00654 (Western District of Michigan), and relating to the action styled *Magna Electronics Inc. v. TRW Automotive Holdings Corp. et al.*, Civil Action No. 1:13-cv-00324 (Western District of Michigan).
Testifying Expert for Magna Electronics
Completed in February 2016.
(Expert reports submitted, and deposed.)

Matter: Patent Infringement in Electronic Circuits
Law Firm: Ropes and Gray
Case Name: Certain Devices Containing Non-Volatile Memory and Products Containing the Same (USITC Inv. Nos. 337-TA-922)
Testifying Expert for Spansion Inc.
Completed in February 2015.
(Expert reports submitted.)

Matter: Trade Secret Misappropriation in Software Method for Cable Television Advertisement
Law Firm: Brownstein Hyatt Farber Schreck
Case Name: Cross MediaWorks v. EMT Holdings, USDC Southern District of New York, Case No. 1:14-cv-00561-VSB
Testifying Expert for Cross MediaWorks.
Completed in April 2015.
(Testified during injunction hearing.)

Matter: Patent Infringement in Vehicular Electronics
Law Firm: Steptoe and Johnson
Case Name: Certain Vision-Based river Assistance System Cameras and Components Thereof (USITC Inv. Nos. 337-TA-899 and 907)
Testifying Expert for Magna Electronics
Completed in February 2015.
(Expert reports submitted, deposed, and testified during trial.)

Matter: Patent Infringement for Vehicular System
Law Firm: Susman Godfrey
Case Name: Eagle Harbor Holdings, LLC, and Mediustech, LLC, v. Ford Motor Company, 3:11-cv-05503-BHS (U.S.D.C. Western District of Washington at Tacoma)
Testifying Expert for Mediustech.
Completed in March 2015.
(Expert reports submitted, deposed, and testified during trial.)

Matter: Patent Infringement for Communication Networks
Law Firm: Davis Polk & Wardwell LLP
Case Name: Sprint Communications Company L.P., v. Comcast Cable Communications, LLC, Comcast IP Phone, LLC, and Comcast Phone of Kansas, LLC. 2:11-cv-02684-KHV-DJW (U.S.D.C. Kansas)
Testifying Expert for Comcast.
Retained in March 2012.
(Expert reports submitted, and deposed.)

Matter: Patent Infringement for Communication Networks
Law Firm: Quinn Emanuel
Case Name: France Telecom S.A. v. Marvell Semiconductor, Inc., 12-Civ-4986 (S.D.N.Y.)
Testifying Expert for Marvell.
Completed in September 2014.
(Expert reports submitted, deposed, and testified during trial.)

Matter: Wireless Image Distribution
Law Firm: Jones Day
Case Name: *Inter Partes* Review of U.S. Patent No. 8,437,797
Expert for Google Inc.
Completed in November 2014.
(Expert declaration submitted.)

Matter: Nonvolatile Semiconductor Memories
Law Firm: Jones Day
Case Name: *Inter Partes* Review of U.S. Patent Nos. 8,301,833 and 8,516,187
Expert for SanDisk.
Completed in May 2014.
(Expert declaration submitted.)

Matter: Communication Protocols for Wireless Device
Law Firm: Dorsey & Whitney, LLP
Case Name: Certain Point-To-Point Network Communication Devices and Products Containing Same (USITC Inv. No. 337-TA-892)
Testifying Expert for Toshiba
Completed in May 2014.
(Expert reports submitted, and deposed.)

Matter: Patent Infringement for Wireless Networks
Law Firm: Ropes and Gray
Case Name: In the Matter of Certain Wireless Devices With 3G and/or 4G Capabilities and Components Thereof (USITC Inv. No. 337-TA-868) InterDigital Comms., Inc. v. Huawei Techs. Co., Ltd., No. 13-00008 (D. Del., filed January 2, 2013), InterDigital Comms., Inc. v. ZTE Corp., No. 13-00009 (D. Del., filed January 2, 2013), InterDigital Comms., Inc. v. Nokia Corp., No. 1:13-cv-00010 (D. Del.,

filed January 2, 2013), InterDigital Comms., Inc. v. Samsung Elec. Co., Ltd., No. 13-00011 (D. Del., filed January 2, 2013)
Testifying Expert for Joint Defense Group.
Completed in February 2014.
(Expert reports submitted, deposed, and testified during trials.)

Matter: Patent Infringement for Mobile Communication
Law Firm: Finnegan, Henderson, Farabow, Garrett & Dunner, L.L.P.
Case Name: Certain Digital Media Devices, Including Televisions, Blu-Ray Disc Players, Home Theater Systems, Tablets and Mobile Phones, Components Thereof and Associated Software (USITC Inv. No. 337-TA-882)
Testifying Expert for LG Electronics, Inc.
Completed in February 2014.
(Expert reports submitted, deposed, and testified during trial.)

Matter: Patent Infringement for Wireless Networks
Law Firm: Vinson & Elkins LLP
Case Name: Wi-LAN USA, Inc. and Wi-LAN, Inc. v. Telefonaktiebolaget LM Ericsson and Ericsson, Inc. (USDC: Southern District of FL - Case #1: 12-cv-23569), Wi-LAN USA, Inc. and Wi-LAN, Inc. v. Alcatel-Lucent USA, Inc. (USDC: Southern District of FL - Case #1: 12-cv-23568-Altonaga/Simonton)
Testifying Expert for Wi-LAN.
Completed in May 2015.
(Expert reports submitted, and deposed.)

Matter: Patent Infringement for Data Storage
Law Firm: Ropes and Gray, Weil Gotshal
Case Name: Summit Data Systems, LLC v. EMC Corporation., et al. 1:10-cv-00749-GMS (U.S.D.C. Delaware)
Testifying Expert for EMC Corporation and Netapp, Inc.
Completed in December 2012.
(Expert reports submitted, and deposed.)

Matter: Patent Infringement for Wireless Mobile Device
Law Firm: Ashurst Australia
Case Name: Samsung v. Apple, Australian Federal Court Proceeding No. NSD 1243 of 2011
Testifying Expert for Samsung Electronics.
Completed in December 2012.
(Expert reports submitted, deposed, and testified during trial.)

Matter: Patent Infringement for Wireless Mobile Devices
Law Firm: Quinn Emanuel
Case Name: Apple Inc. v. Samsung Electronics Co., Ltd., et al., 4:11-cv-01846-LHK (N.D. Cal.) and Samsung Electronics Co., Ltd., et al. v. Apple Inc., 4:11-cv-02079 (N.D. Cal.)
Testifying Expert for Samsung Electronics.

Completed in July 2012.
(Expert reports submitted, and deposed.)

Matter: Patent Infringement for Wireless Mobile Device
Law Firm: Quinn Emanuel
Case Name: Certain Electronic Devices, Including Wireless Communication Devices, Portable Music And Data Processing Devices, And Tablet Computer, U.S.I.T.C. Inv. No. 337-TA-794
Testifying Expert for Samsung Electronics.
Completed in June 2012.
(Expert reports submitted, deposed, and testified during trial.)

Matter: Patent Infringement for Portable Storage Device
Law Firm: White and Case
Case Name: CERTAIN UNIVERSAL SERIAL BUS ("USB") PORTABLE STORAGE DEVICES, INCLUDING USB FLASH DRIVES AND COMPONENTS THEREOF, US International Trade Commission Investigation No. 337-TA-788
Testifying Expert Witness for Trek
Completed in May 2012.
(Expert reports submitted, and deposed.)

Matter: Copyright Infringement for Petroleum Processing Software
Law Firm: Osha Liang LLP
Case Name: Aspen Technology, Inc. v. Tekin A. Kunt and M3 Technology, Inc., Case Number: H-10-1127, US District Court, Texas, Houston Division.
Testifying Expert for M3 Technology, Inc.
Completed in May 2012.
(Expert reports submitted, deposed, and testified during trial.)

Matter: Trade Secret Misappropriation for DC-DC converter
Law Firm: Covington & Burling, Haynes Boone
Case Name: Certain DC—DC Controllers and Products Containing Same, US International Trade Commission Investigation No. 337-TA-698
Testifying Expert for UPI.
Completed in March 2012.
(Expert reports submitted, deposed, and testified during trial.)

Matter: Patent Infringement for Parallel Processor
Law Firm: Orrick, Herrington, & Sutcliffe. Kirkland and Ellis.
Case Name: BIAX Corporation v. Nvidia and Sony Civil Action No. 09-cv-01257-PAB-MEH
Testifying Expert for Nvidia and Sony
Completed in March 2012.
(Expert reports submitted, and deposed.)

Matter: Patent Infringement for Call Center Technology
Law Firms: Duffy, Sweeney, and Scott. Foley Lardner.

Case Name: Ronald Katz Technology Licensing v. Citizens Financial Group 7-ML-1816-C RGK (FFM)
Testifying Expert Witness for Citizens Financial Group.
Completed in 2011.
(Expert reports submitted, and deposed.)

Matter: Patent Infringement for Storage Area Network
Law Firm: DLA Piper
Case Name: Network Appliance, Inc., v. Sun Microsystems, Inc., Case Number: C-07-06053 EDL, US District Court, Northern District of California, San Francisco Division.
Testifying Expert for Sun Microsystems, Inc.
Completed in 2010.
(Expert reports submitted, and deposed.)

Matter: Patent Infringement for Flat Panel Display Controller
Law Firm: Jones Day
Case Name: Certain Video Displays, Components Thereof, and Products Containing Same, US International Trade Commission Investigation No. 337-TA-687
Testifying Expert for Vizio, Inc.
Completed in 2010.
(Expert reports submitted, deposed, and testified during trial.)

Matter: Patent Infringement for Call Center Technology
Law Firms: Foley Lardner
Case Name: Ronald Katz Technology Licensing v. US Bank 7-ML-1816-C RGK (FFM)
Testifying Expert Witness for US Bank
Completed in May 2009.
(Expert reports submitted, and deposed.)

Matter: Patent Infringement for USB to VGA Converter
Law Firm: Wang Hartmann, Gibbs, & Cauley, P.C.
Case Name: Displaylink Corporation v. Magic Control Technology Corporation, Case No. 5:07-CV-01998-RMW, US District Court, Northern District of California, San Francisco Division.
Testifying Expert for Magic Control Technology Corporation
Completed in 2009.
(Expert reports submitted, and deposed.)

Matter: Patent Infringement for Flash Memory
Law Firm: Jones Day and Wilson Sansini
Case Name: Certain Flash Memory Controllers, Drives, Memory Card, and Media Players and Products Containing Same. US International Trade Commission Investigation No. 337-TA-619
Testifying Expert for SanDisk Corporation.
Completed in 2008.
(Expert reports submitted, deposed, and testified during trial.)

Matter: Patent Infringement for Semiconductor Packaging
Law Firm: Jones Day
Case Name: Certain Semiconductor Chips with Minimized Chip Package Size and Products Containing the Same. US International Trade Commission Investigation No. 337-TA-605
Testifying Expert for Freescale Semiconductor
Completed in 2008.
(Expert reports submitted, deposed, and testified during trial.)

Matter: Patent Infringement for Automatic Switching System
Law Firms: Jones Day, and Heller Ehrman, LLP.
Case Name: ATEN International Co., Ltd and ATEN Technology, Inc. v. Belkin Corporation, Belkin Logistics, Inc. and Emine Technology Co., Ltd. US International Trade Commission Investigation No. Ltd 337-TA-589
Testifying Expert for Belkin Corporation, Belkin Logistics, Inc., and Emine Technology Co., Ltd.
Completed in 2007.
(Expert reports submitted, deposed, and testified during trial.)

Matter: Patent Infringement for Dual Mode Communication
Law Firm: Wilmer Cutler Pickering Hale and Dorr, LLP
Case Name: Broadcom Corporation v. Qualcomm Incorporated SACV05-467-JVS (RNBx)
Testifying Expert Witness for Broadcom Corporation
Completed in 2007.
(Expert reports submitted, deposed, and testified during trial.)

Exhibit B

Exhibit B Materials Considered

In forming the opinions I have expressed in this declaration, I have considered the materials cited in the declaration, including but not limited to the following:

- U.S. Patent No. 6,941,156 ("the '156 Patent"), and prosecution history
- U.S. Patent No. 7,957,450 ("the '450 Patent"), and prosecution history
- U.S. Patent No. 8,416,862 ("the '862 Patent"), and prosecution history
- Joint Claim Construction Chart, Worksheet, and Hearing Statement Pursuant to P.L.R. 4.2 (April 19, 2019), and intrinsic and extrinsic evidence identified therein
- BNR's Patent L.R. 3.6 Amended Disclosure of Asserted Claims and Infringement Contentions (April 19, 2019)
- Matrix Computations, third edition, by Gene H. Golub and Charles F. Van Loan, 1996. ("Golub and Van Loan"), DEFBNRPA_000006794.
- Wireless vs. Wired. How Software Define Radio technology addresses issues related to the use of wireless networks when compared to a wired solution White Paper, Lexycom Technologies, Inc. (May 2005). BNR SDCA00037995 – BNR-SDCA00038005.
- Igor S. Simic, Evolution of Mobile Base Station Architectures, Microwave Review at 31 (June 2007). BNR-SDCA00037973 – BNR-SDCA00037979.
- Rajeesh Kutty, A Simple Baseband Processor for RF Transceivers, Analog Devices. BNR-SDCA00000037967 – BNR-SDCA00037972.

Exhibit C

US006941156B2

(12) **United States Patent**
Mooney

(10) **Patent No.: US 6,941,156 B2**
(45) **Date of Patent: Sep. 6, 2005**

(54) **AUTOMATIC HANDOFF FOR WIRELESS PICONET MULTIMODE CELL PHONE**

(75) Inventor: **Philip D. Mooney**, Sellersville, PA (US)

(73) Assignee: **Agere Systems Inc.**, Allentown, PA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 835 days.

(21) Appl. No.: **09/888,493**

(22) Filed: **Jun. 26, 2001**

(65) **Prior Publication Data**

US 2002/0198020 A1 Dec. 26, 2002

(51) **Int. Cl.**[7] **H04M 1/00**
(52) **U.S. Cl.** **455/553.1**; 455/552.1
(58) **Field of Search** 455/403, 426.1, 455/552.1, 553.1

(56) **References Cited**

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6,317,582 B1 * 11/2001 Yoshinaga 455/11.1
6,363,246 B1 * 3/2002 Williams et al. 455/403
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Primary Examiner—Bing Q. Bui

(57) **ABSTRACT**

A technique and apparatus for transferring a communication link between two different modes of a multimode cell phone. For instance, an active telephone call using a cordless telephone RF communication link may be automatically switched (with user prompt if desired) to a cell phone call when desired (e.g., when the cordless telephone goes out of range of its base unit), and vice versa. CallerID Type 2 and Call Waiting may be used to switch the far end telephone from one line to the other with minimal (or even unnoticeable) disruption to the participants or content of the telephone connection.

19 Claims, 6 Drawing Sheets

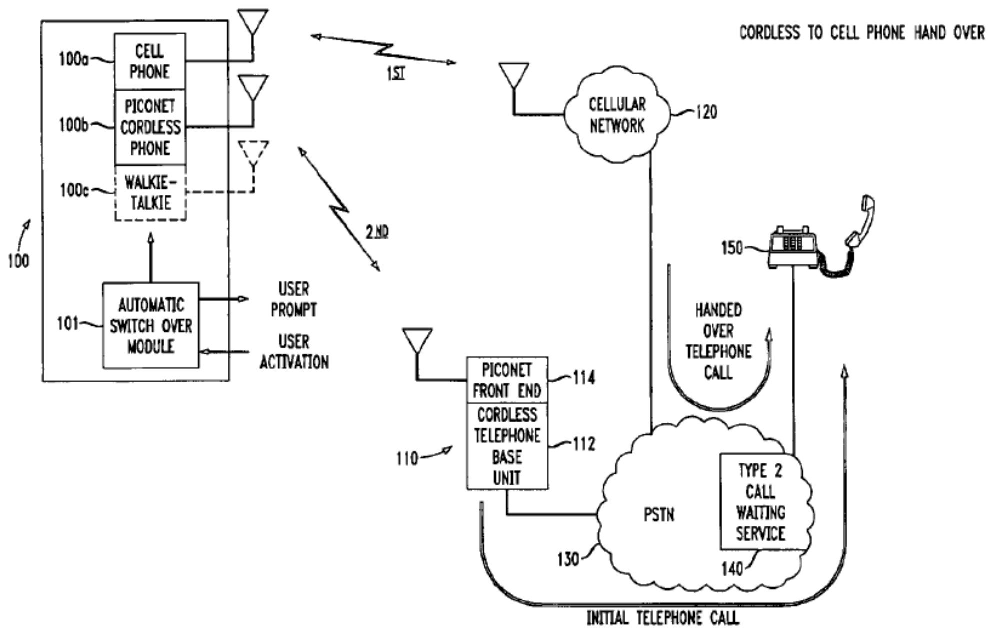


FIG. 1

CORDLESS TO CELL PHONE HAND OVER

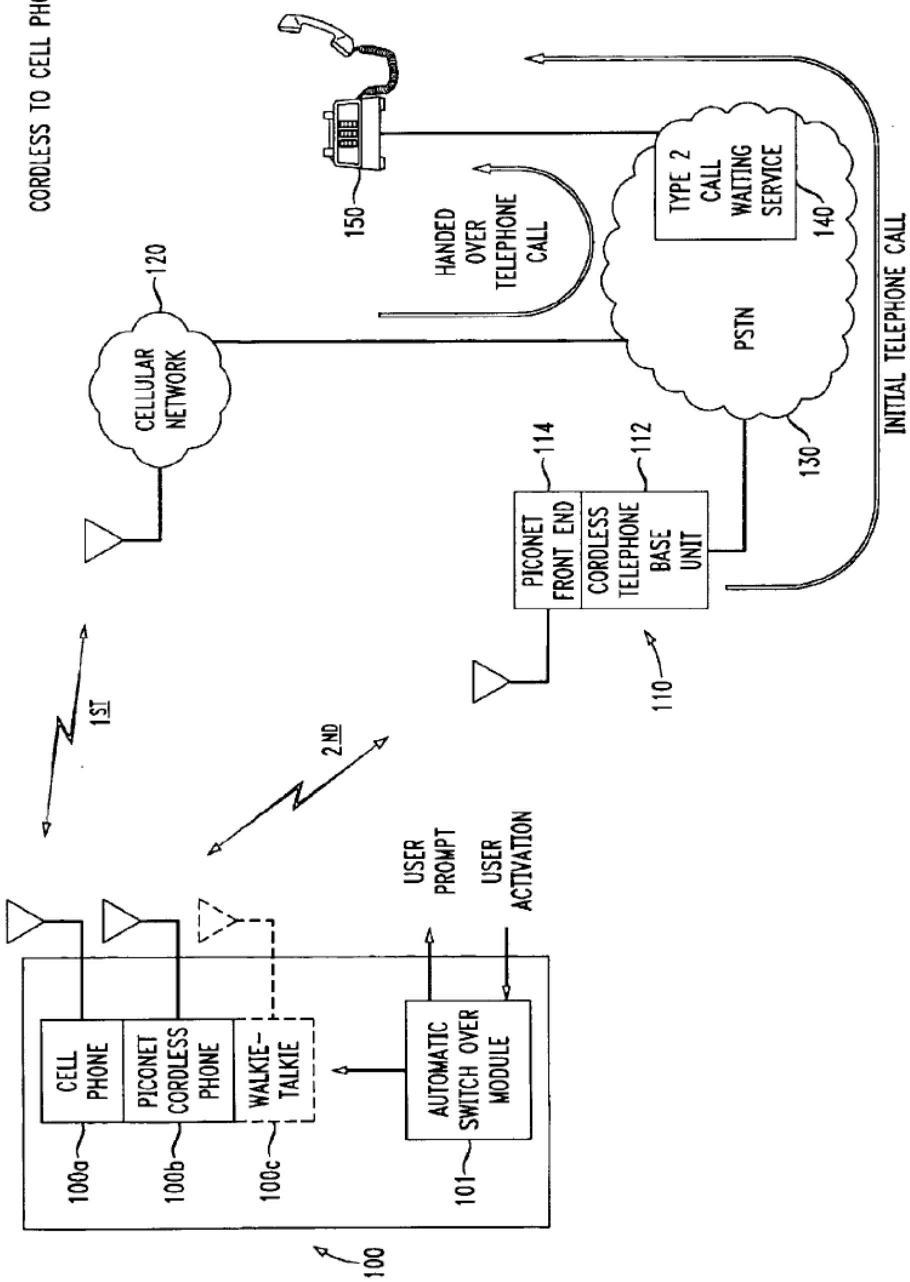


FIG. 2

CORDLESS TO CELL PHONE HAND OVER

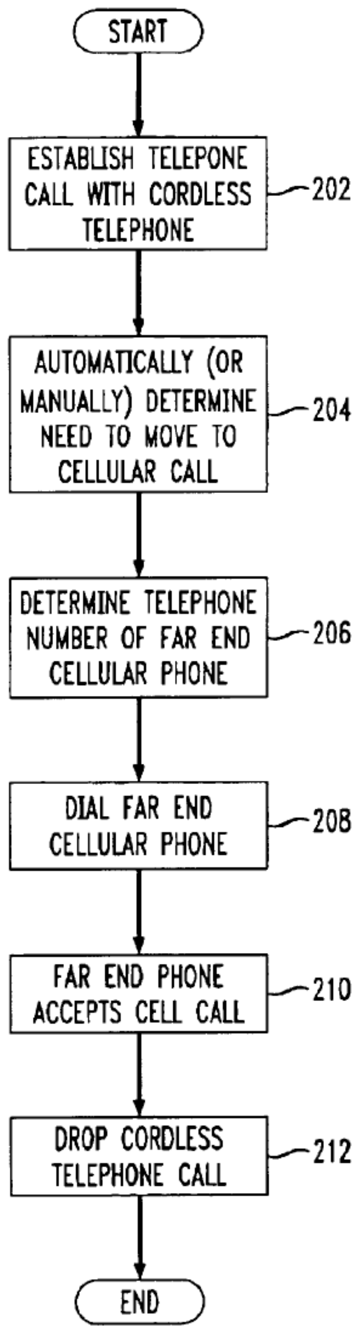


FIG. 3

WALKIE-TALKIE TO CELL PHONE HAND OVER

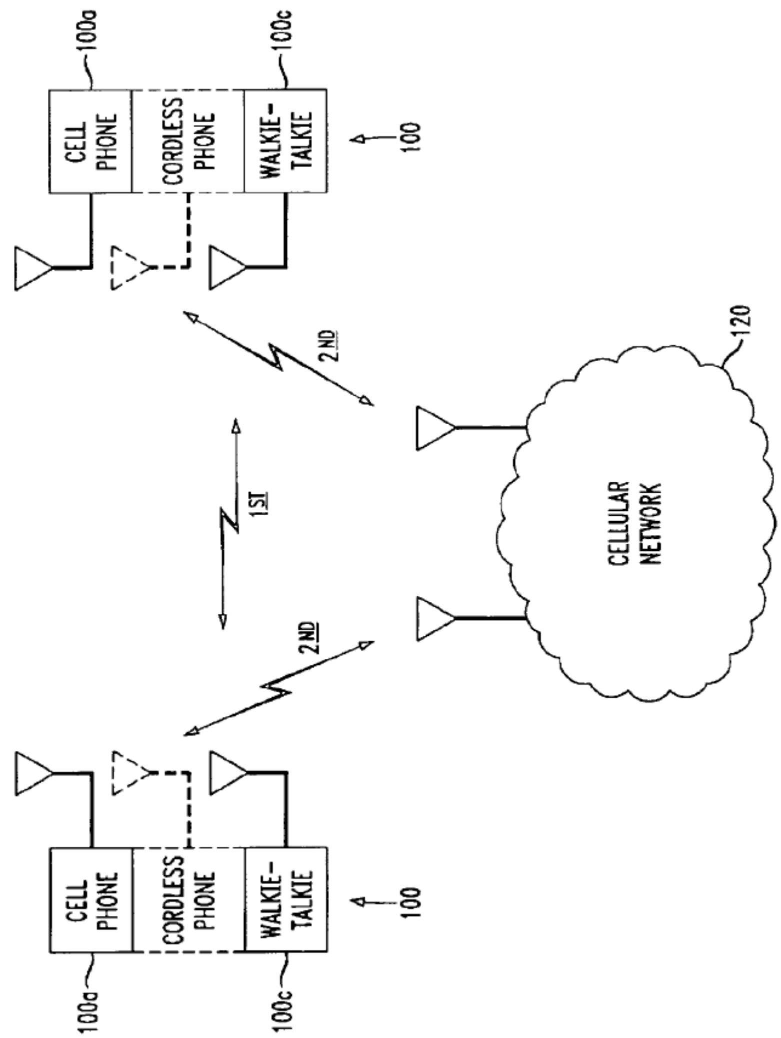


FIG. 4

WALKIE-TALKIE TO CELL PHONE HAND OVER

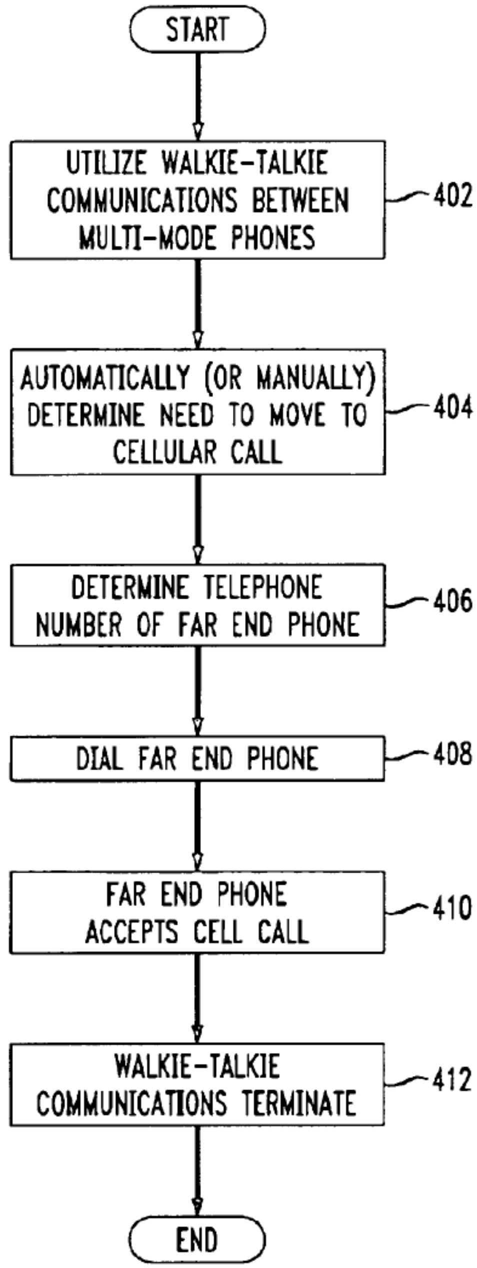


FIG. 5

WALKIE-TALKIE TO CORDLESS HAND OVER

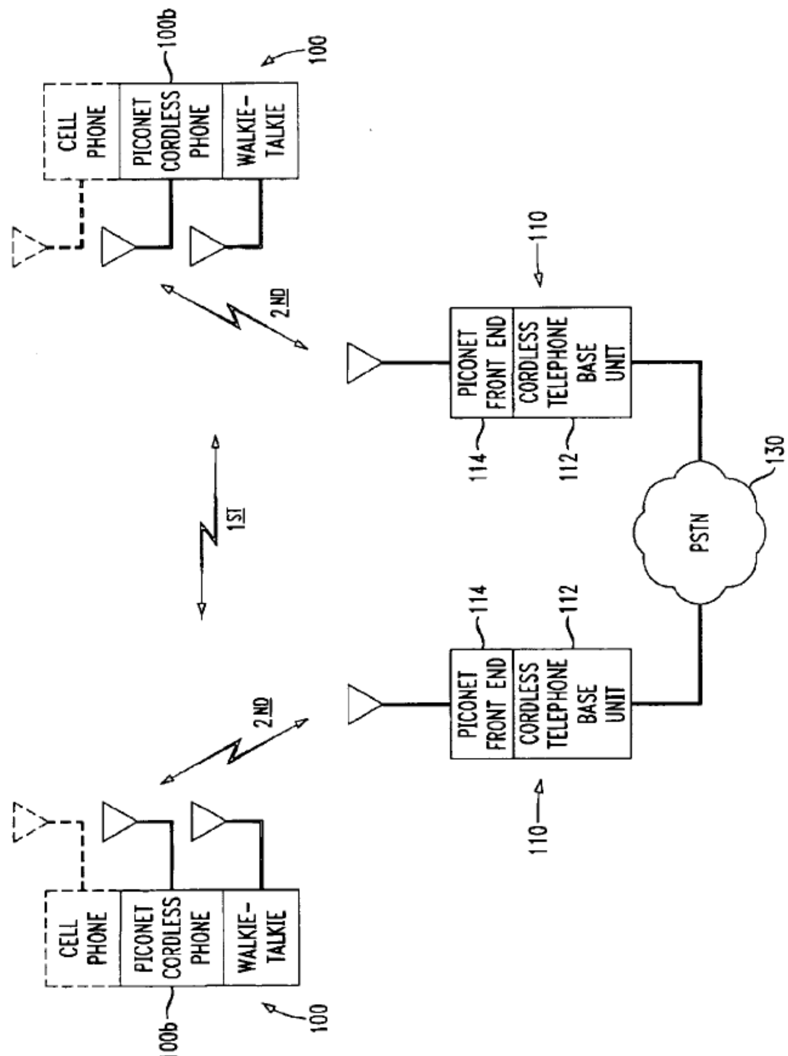
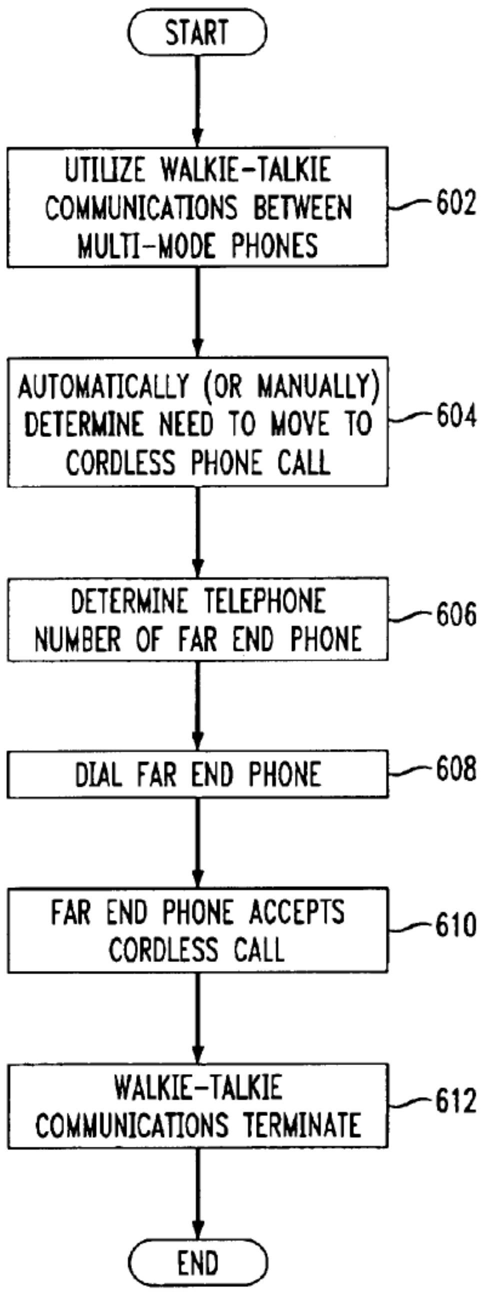


FIG. 6

WALKIE-TALKIE TO CORDLESS HAND OVER



AUTOMATIC HANDOFF FOR WIRELESS PICONET MULTIMODE CELL PHONE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention generally relates to piconet wireless networks. More particularly, it relates to the use of a combination 3-in-1 cell phone/cordless telephone/walkie-talkie device.

2. Background of Related Art

One of the new and useful ideas coming out of BLUETOOTH technology is the 3-in-1 cell phone, where a cell phone has advanced and additional capabilities to operate as a cordless telephone when near a matching cordless telephone base station, or to work as a walkie-talkie when near another similarly capable handset. This provides a cell phone that has advantages over competitors' cell phones which are not similarly capable, including the ability and convenience of storing all phone book data, calling history and user preferences.

Using such systems, a cell phone user has the ability and convenience of accessing a cordless telephone base station when, e.g., arriving home. Having such access, a cordless telephone user might make telephone calls using their cell phone handset accessing their cordless telephone base unit at times when they might not otherwise use their cell phone handset, e.g., when at home in the vicinity of a cordless telephone.

Convenience aside, a 3-in-1 cell phone conventionally provides establishment of a telephone call with a wireless cell phone network, or with a local cordless telephone, depending upon which mode the phone is in. To operate the 3-in-1 cell phone in a cordless telephone mode, the 3-in-1 cell phone is manually switched to a cordless telephone mode by the user, and then a telephone call is made from the base unit. Similarly, to operate a 3-in-1 cell phone in a cellular mode, the 3-in-1 phone is manually switched to a cellular mode, and then a cellular telephone call is established from the handset. To switch between cordless and cellular modes, the user must first terminate any existing telephone call, and then manually switch the mode of the 3-1 telephone.

There is a need in a 3-in-1 cell phone which provides smooth switchover and interaction between separate modes of operation.

SUMMARY OF THE INVENTION

In accordance with the principles of the present invention, a multimode cell phone comprises a cell phone functionality, and an RF communication functionality separate from the cell phone functionality. An automatic switch over module is in communication with both the cell phone functionality and the RF communication functionality. The automatic switch over module operates to switch a communication path established on either the cell phone functionality or the RF communication functionality, with another communication path established on the other of the cell phone functionality and the RF communication functionality.

A method of automatically switching between a first type RF communication link and a second type RF communication link different from the first type RF communication link, comprising participating in the first type RF communication link. An availability of the second type RF communication link is sensed, and if available, the second type RF communication link is established while the first type RF communication link remains active. The parties participating in the first type RF communication link are switched to active utilization of the second type RF communication link.

BRIEF DESCRIPTION OF THE DRAWINGS

Features and advantages of the present invention will become apparent to those skilled in the art from the following description with reference to the drawings, in which:

FIG. **1** shows a multimode cell phone handing over a telephone call from a cordless mode to a cellular mode, in accordance with the principles of the present invention.

FIG. **2** shows an exemplary process for handing over a telephone call from the cordless mode of a multimode cell phone to a cellular mode of the multimode cell phone, in accordance with the principles of the present invention.

FIG. **3** shows a multimode cell phone handing over a walkie-talkie conversation to a cellular telephone call, in accordance with the principles of the present invention.

FIG. **4** shows an exemplary process for handing over a walkie-talkie conversation to a cellular telephone call handled by a cellular mode of a multimode cell phone, in accordance with the principles of the present invention.

FIG. **5** shows a multimode cell phone handing over a walkie-talkie conversation to a cordless telephone call, in accordance with the principles of the present invention.

FIG. **6** shows an exemplary process for handing over a walkie-talkie conversation to a cordless telephone call handled by a cordless telephone mode of a multimode cell phone, in accordance with the principles of the present invention.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

More and more home and office devices are designed to form piconets, or small wireless networks. One popular piconet standard is commonly referred to as a BLUETOOTH™ piconet. Piconet technology in general, and BLUETOOTH™ technology in particular, provides peer-to-peer communications over short distances.

The wireless frequency of piconets may be 2.4 GHz as per BLUETOOTH™ standards, and/or typically have a 20 to 100 foot range. The piconet RF transmitter may operate in common frequencies that do not necessarily require a license from the regulating government authorities, e.g., the Federal Communications Commission (FCC) in the United States. Alternatively, the wireless communication can be accomplished with infrared (IR) transmitters and receivers, but this is less preferable because of the directional and visual problems often associated with IR systems.

A plurality of piconet networks may be interconnected through a scatternet connection, in accordance with BLUETOOTH™ protocols. BLUETOOTH™ network technology may be utilized to implement a wireless piconet network connection (including scatternet). The BLUETOOTH™ standard for wireless piconet networks is well known, described in the BLUETOOTH™ specification, version 1.1, publicly available from the web site www.bluetooth.com. The entire BLUETOOTH™ specification (core and profiles), version 1.1, in particular the Cordless Telephony Profile portion of version 1.1 of the Profiles, is explicitly incorporated herein by reference,.

The BLUETOOTH™ specification defines a Cordless Telephony Profile. In particular, Part K:3 of the BLUETOOTH™ specification version 1.1, Profiles, pages 99–144, defines the features and procedures that are required for interoperability between different cordless telephones, e.g., between remote handsets and corresponding base units.

The '3-in-1' phone is a solution for providing an extra mode of operation to cellular phones, using BLUETOOTH™ as a short-range bearer for accessing fixed network telephony services via a base station. The 3 functions include making telephone calls via a base station (i.e., cordless telephone mode), making direct intercom calls between two terminals (e.g., between two cellular telephone handsets), and, of course, making an otherwise conventional cellular phone call.

The Cordless Telephony Profile defines two roles: Gateway (GW) and Terminal (TL). The Gateway acts as a terminal endpoint from the external network point of view and handles all Interworking towards that network. The Gateway is the central point with respect to external calls, which means that it handles all call set-up requests to/from the external network. The Terminal is the wireless user terminal (e.g., the remote handset of a cordless telephone). The Cordless Telephony profile supports a small number (i.e., less than 7) of terminals, or 3 active voice terminals. In accordance with the principles of the present invention, the multimode 3-in-1 cell phone includes the Cordless Telephony Profile of BLUETOOTH™ capability.

The present invention provides a technique for transferring an active telephone call from cordless telephone mode to cell phone mode (and vice versa) in a 3-in-1 cell phone. In particular, in accordance with the principles of the present invention, CallerID Type2 and Call Waiting are used to switch the far end telephone from one line to the other with minimal (or even unnoticeable) disruption to the participants or content of the telephone connection.

Using conventional 3-in-1 phones, there is no provision for automatically transferring a call from a cordless handset mode to a cell phone mode (e.g., when a user is leaving a household where a matching cordless telephone base unit). Similarly, there is conventionally no automatic way to transfer a telephone call from a cell phone to a cordless telephone base unit when the user returns home. Certainly, a user could manually hang up the 3-in-1 cell phone in one mode (e.g., cordless telephone mode) and initiate a new telephone call using a new mode (e.g., cell phone mode). However, this would require manual operations performed by the user, being a bit of a nuisance to the user prone to error, and also a significant and potentially lengthy disruption to the underlying telephone call.

FIG. **1** shows a multimode cell phone handing over a telephone call from a cordless mode to a cellular mode, in accordance with the principles of the present invention.

In particular, as shown in FIG. **1**, a multimode cell phone **100** includes multiple functional modes, e.g., a cell phone mode **100***a*, a piconet cordless telephone **100***b*, and a walkie-talkie mode **100***c*.

Importantly, an automatic switch over module **101** is in communication with each communication path functionality, e.g., with the cell phone functionality **100***a*, the piconet cordless telephone functionality **100***b*, and the walkie-talkie functionality **100***c*. The desired mode of the multimode cell phone **100** may be controlled through suitable communications with each communication path functionality **100***a*–**100***c*.

Preferably, more than one mode of the multimode cell phone **100** may operate simultaneously, allowing the establishment of a secondary communication path in the background, allowing easy and quick switch over as desired or required. For instance, while operating in a cell phone mode, the automatic switch over module **101** of the multimode cell phone **100** may detect walkie-talkie communication activity from the far party's multimode cell phone **100**, and establish a communication link therebetween even while the two parties remain in a cell phone conversation.

In the cordless telephone mode, the multimode cell phone **100** communicates between handset unit **100** and a matching piconet cordless telephone base unit **110** using a suitable piconet front end **114** in the base unit **110** and a matching piconet front end within the multimode cell phone **100**.

For explanation purposes, FIG. **1** depicts an established telephone call between the multimode cell phone **100** and a far end telephone **150** (which in the example is a landline telephone accessed through a cellular network). Of course, the far end telephone can be any telephonic device, multimode or single mode.

Once the multimode cell phone **100** extends beyond its acceptable range, the telephone call would ordinarily be dropped, perhaps involuntarily. However, in accordance with the principles of the present invention, the telephone call between the multimode cell phone **100** and the far end telephone **150** is automatically re-established using the cellular network **120**. By automatically changing the mode of the multimode cell phone **100** (preferably subsequent to a prompt to the user for permission to transfer), the conversation or other communication between the parties is transferred to the newly established cell phone call.

While FIGS. **1** and **2** depict the transfer of a telephone call from a cordless telephone call to a cellular telephone call, the converse is preferably also possible. For example, a person using a cell phone having 3-in-1 capability in accordance with the principles of the present invention is on their way home while talking on their 3-in-1 cell phone in cellular (or other wireless network) mode. Assume that that person then arrives at their home and becomes within range of the cordless telephone base station that is matched to the cordless telephone mode of the 3-in-1 cell phone.

In accordance with the principles of the present invention, an automated procedure may be initiated by the user of the multimode cell phone **100** at the press of a designated button. The user may be prompted about impending loss of signal or otherwise loss of the established telephone call, and may be prompted to permit establishment of and ultimately transfer to an alternative type communication path (e.g., a cellular phone call). In response, the user preferably activates a suitable button, e.g., a dedicated button called, e.g., "Switch to Cell Network", or simply "Switch Communication Path". Of course, the transfer may be entirely automated without requiring input from the user, within the scope of the invention.

FIG. **2** shows an exemplary process for handing over a telephone call from the cordless mode of a multimode cell phone to a cellular mode of the multimode cell phone, in accordance with the principles of the present invention.

In particular, as shown in step **202** of FIG. **2**, a cordless telephone call is established using a cordless telephone mode of the multimode cell phone **100**.

In step **204**, the need (or desire) to change communication modes to a cellular mode is determined.

In step **206**, the telephone number of the far end telephone **150** (or another suitable phone accessible to the far end party) is determined, e.g., using a call related information service such as a CallerID type service provided by the PSTN **130** (FIG. **1**).

In step **208**, the determined telephone number of the far end telephone **150** is dialed, and passes through to the far end telephone **150** using, e.g., a Call Waiting type service **140**.

In step **210**, the user of the far end telephone **150** accepts the newly incoming telephone call in response to their Call Waiting and/or Type 2 CallerID service.

In step **212**, the old communication path (in this case the cordless telephone call) is dropped, perhaps after a desirable delay (e.g., after 5 seconds).

The converse of the example of FIGS. **1** and **2** is also possible. For instance, the multimode cell phone **150** may move from a cell phone call to a cordless telephone call, e.g., once the multimode cell phone **100** becomes within range of its matching base unit **110**. In this case, the multimode cell phone **100** automatically establishes a wireless connection with the cordless telephone base station **110** using, e.g., a wireless piconet protocol conforming to the BLUETOOTH™ standard. Using the wireless cordless telephone communication path established between the multimode cell phone **150** and its base unit **110**, a suitable telephone number relating to the far end party may be determined and passed to the cordless telephone functionality of the multimode cell phone **100**.

Preferably, the initial caller in the first telephone call controls the re-establishment of an alternative mode communication path. For instance, in the disclosed embodiment, the far end party's telephone number is obtained by the multimode cell phone **150** that initiated the first telephone call (i.e., who called whom).

Telephone numbers for the far end party may be recalled from a last number dialed functionality of the multimode cell phone **150**. However, call related information such as CallerID information may be used to allow a far end party to themselves initiate a communication path mode transfer.

In the event that both parties attempt to initiate a communication mode change (e.g., from cordless to cellular), conventional collision detect and variously delayed retry schemes may be utilized.

The far end party's telephone number may be obtained for transfer between cordless and cellular telephone modes, e.g., from last number dialed memory (if the user initiated the call), or from the last number received in Caller ID memory (if the current call was incoming from the far end party).

In the given example, the cordless telephone base station **110** then goes off hook and dials the telephone number of the far end party, whether or not the far end party initiated the transferred telephone call. In this example, from the far-end user's perspective, the far end user hears that there is a call coming in (e.g., using a Call Waiting service) and may or may not review CallerID information such as the telephone number and/or name of the calling party, before they accept the new call. Using Call Waiting type service, the far end party would accept the new communication mode by simply activating a FLASH button and abandoning the first telephone call (which will eventually be dropped either by the base unit **110** of the calling party such as is shown in step **212** of FIG. **1**, or by the telephone company if the telephone company senses a lack of activity on the abandoned telephone call. To this end, the cordless telephone base unit **110** may notify the handset that the new communication path has been established and accepted, allowing the base unit **110** to finally switch the audio path from the cell phone link to the BLUETOOTH™ cordless telephone link and then disconnect the cell phone call.

In a more automated embodiment of a 3-in-1 phone having automatic handoff capability between modes in accordance with the principles of the present invention, the far end phone **150** includes a capability to sense when a switch between communication path modes is occuring on the near end, and if so to automatically activate a flash signal on the telephone line.

The automatic handoff capability may be implemented using a lookup table including entries relating to alternate telephone numbers, e.g., associated cell phone numbers, land line numbers, etc. However, care should be taken to avoid the vulnerability to erroneous communication path switching.

A safer, alternative approach implements a predetermined signaling tone (e g. a DTMF tone sent from the near end (switching) phone and a detector on the far end phone **150** recognizing it and preparing to flash when the new call comes in. Of course, there could be a combination of both. Let's look at this example.

A person on their way home is talking to a co-worker on their multimode cell phone **100** (in cell phone mode). That person then arrives home and sits down near their cordless base station **110**. Preferably, the multimode cell phone **100** maintains a configuration such that when a cordless telephone link (e.g., a piconet BLUETOOTH™ link of good quality) has been established with the cordless base for a given length of time (e.g., for at least two minutes), then the multimode cell phone handset **100** will allow switch over to the cordless telephone call and ultimately drop or terminate the original cell phone call.

To accomplish this, the multimode cell phone **100** may send, e.g., a quick DTMF "7" followed by a DTMF "9" (i.e., representing the characters "SW") notifying the near end user and the far end phone **150** (and user) that a switch is about to happen. The far end phone **150** would remain ready for a switch over for a given length of time, e.g., for 20 seconds. The multimode cell phone **100** makes the alternate phone call as described above. After the far end phone receives the new call, it checks the call related information (e.g., CallerID data) against entries in a suitable lookup table, and if it finds a match, then automatically flashes the telephone line on the original telephone call. The near end phone, as in the first example, is then notified that the second call has gone through, allowing the conversation to continue on a switched over communication path.

In the unlikely event that the switchover does not succeed, the switchover is preferably delayed (e.g., for 10 seconds or more) to allow the users to switch back to the initial telephone call or communication path.

Similar to the above examples, the multimode cell phone **100** may switch from cordless mode to cell phone mode when the user wishes to leave the proximity of the cordless telephone base unit **110**. For instance, manual activation of a suitable button, or automatic detection of the quality of the RF link (e.g., the BLUETOOTH™ piconet link) below a preset level may initiate this feature.

The present invention is equally applicable to a 2-in-1 phone as it is to a 3-in-1 or more mode phone. For instance, automatic switching from a walkie-talkie mode can be performed without the need to control a telephone network.

For instance, FIG. **3** shows a multimode cell phone **100** handing over a walkie-talkie conversation to a cellular telephone call, in accordance with the principles of the present invention.

In particular, as shown in FIG. **3**, a multimode cell phone **100** is initially operating in a walkie-talkie mode over a 1^{st} communication path to another multimode cell phone **100**. Thereafter, at a desired point (e.g., when the walkie-talkies reach the limit of their range) switchover to the cellular network **120** is initiated, either manually by the user, or automatically but preferably with a prompt to the user before completion.

FIG. **4** shows an exemplary process for handing over the walkie-talkie conversation to the cellular telephone call handled by the cellular mode of the multimode cell phones **100** (or by a separate cell phone at the far end), in accordance with the principles of the present invention.

In particular, as shown in step **402** of FIG. **4**, the walkie-talkie modes **100***c* of the multimode cell phones **100** are utilized.

In step **404**, the need to initiate, establish and switch over to another mode (e.g., to a cellular phone call) is determined, either automatically or manually, by an appropriate processor in the multimode cell phone **100**.

In step **406**, the telephone number of the far end phone is determined.

In step **408**, the far end phone is dialed.

In step **410**, the far end phone receives and accepts the cell phone call using its cell phone functionality **100***a*. Call related information such as CallerID may be used by the far end party to assist in their acceptance of the incoming call while conversing using the walkie-talkie modes **100***c*.

In step **412**, after the cell phone call has been established and accepted by the far end party, switchover to the cell phone call can be accomplished, and walkie-talkie communications between the two multimode cell phones **100** can be terminated.

FIG. **5** shows a multimode cell phone **100** handing over a walkie-talkie conversation to a piconet cordless telephone call, in accordance with the principles of the present invention.

In particular, as shown in FIG. **5**, a multimode cell phone **100** is initially operating in a walkie-talkie mode over a 1^{st} communication path to another multimode cell phone **100**. Thereafter, at a desired point (e.g., when the walkie-talkies reach the limit of their range) switchover to the cellular network **120** is initiated, either manually by the user, or automatically but preferably with a prompt to the user before completion.

The particular frequency band of operation of the walkie-talkie functionality **100***c* may be any suitable range, digital or analog. One preferred frequency band and protocol is the Family Radio System (FRS) band, having an operable range of over 1 mile.

FIG. **6** shows an exemplary process for handing over the walkie-talkie conversation to the cellular telephone call handled by the cellular mode of the multimode cell phones **100** (or by a separate cell phone at the far end), in accordance with the principles of the present invention.

In particular, as shown in step **602** of FIG. **6**, the walkie-talkie modes **100***c* of the multimode cell phones **100** are utilized.

In step **604**, the need to initiate, establish and switch over to another mode (e.g., to a cordless telephone call using a piconet cordless telephone) is determined, either automatically or manually, by an appropriate processor in the multimode cell phone **100**.

In step **606**, the telephone number of the far end phone is determined.

In step **608**, the far end cordless telephone is dialed.

In step **610**, the far end phone receives and accepts the cordless telephone call using its piconet cordless phone functionality **100***b*. Call related information such as CallerID may be used by the far end party to assist in their acceptance of the incoming call while conversing using the walkie-talkie modes **100***c*.

In step **612**, after the cordless telephone call has been established and accepted by the far end party, switchover to the cordless telephone call can be accomplished, and walkie-talkie communications between the two multimode cell phones **100** can be terminated.

The present invention has application in any piconet device, including cell phones, laptop computers, cordless telephones, etc.

While the invention has been described with reference to the exemplary preferred embodiments thereof, those skilled in the art will be able to make various modifications to the described embodiments of the invention without departing from the true spirit and scope of the invention.

What is claimed is:

1. A multimode cell phone, comprising:

a cell phone functionality; and

an RF communication functionality separate from said cell phone functionality;

a module to establish simultaneous communication paths from said multimode cell phone using both said cell phone functionality and said RF communication functionality; and

an automatic switch over module, in communication with both said cell phone functionality and said RF communication functionality, operable to switch a communication path established on one of said cell phone functionality and said RF communication functionality, with another communication path later established on the other of said cell phone functionality and said RF communication functionality.

2. The multimode cell phone according to claim **1**, wherein:

said RF communication functionality is a cordless telephone.

3. The multiphone cell phone according to claim **2**, wherein:

said cordless telephone utilizes a piconet to communicate between a base unit and a matching remote handset.

4. A method of automatically switching between a first type RF communication link at a multimode cell phone and a second type RF communication link at said multimode cell phone different from said first type RF communication link, comprising:

participating in said first type RF communication link;

sensing an availability of said second type RF communication link;

establishing from said multimode cell phone said second type RF communication link while said first type RF communication link remains active at said multimode cell phone; and

switching parties participating in said first type RF communication link to active utilization of said second type RF communication link.

5. The method of automatically switching between a first type RF communication link at a multimode cell phone and a second type RF communication link at said multimode cell phone different from said first type RF communication link according to claim **4**, further comprising, after said switching parties step:

terminating said first type RF communication link.

6. The method of automatically switching between a first type RF communication link at a multimode cell phone and a second type RF communication link at said multimode cell phone different from said first type RF communication link according to claim **4**, further comprising:

prompting a user of said availability of said second type RF communication link.

7. The method of automatically switching between a first type RF communication link at a multimode cell phone and a second type RF communication link at said multimode cell phone different from said first type RF communication link according to claim **4**, wherein:

at least one of said RF communication links is a telephone call.

8. The method of automatically switching between a first type RF communication link at a multimode cell phone and a second type RF communication link at said multimode cell phone different from said first type RF communication link according to claim **4**, wherein:

said first type RF communication link is a cell phone call.

9. The method of automatically switching between a first type RF communication link at a multimode cell phone and a second type RF communication link at said multimode cell phone different from said first type RF communication link according to claim **8**, wherein:

said second type RF communication link is a cordless telephone call.

10. The method of automatically switching between a first type RF communication link at a multimode cell phone and a second type RF communication link at a multimode cell phone different from said first type RF communication link according to claim **9**, wherein:

a cordless telephone used to participate in said cordless telephone call utilizes a piconet to communicate between a cordless telephone base unit and a matching remote handset.

11. The method of automatically switching between a first type RF communication link at a multimode cell phone and a second type RF communication link at a multimode cell phone different from said first type RF communication link according to claim **4**, wherein:

said second type RF communication link is a walkie-talkie link.

12. Apparatus for automatically switching between a first type RF communication link at a multimode cell phone and a second type RF communication link at a multimode cell phone different from said first type RF communication link, comprising:

means for participating in said first type RF communication link;

means for sensing an availability of said second type RF communication link;

means for establishing said second type RF communication link, when said second type RF communication link is sensed to be available by said means for sensing; and

means for switching parties participating in said first type RF communication link to active utilization of said second type RF communication link.

13. The apparatus for automatically switching between a first type RF communication link at a multimode cell phone and a second type RF communication link at said multimode cell phone different from said first type RF communication link according to claim **12**, further comprising:

means for terminating said first type RF communication link after said means for switching switches said parties.

14. The apparatus for automatically switching between a first type RF communication link at a multimode cell phone and a second type RF communication link at said multimode cell phone different from said first type RF communication link according to claim **12**, further comprising:

means for prompting a user of said availability of said second type RF communication link.

15. The apparatus for automatically switching between a first type RF communication link at a multimode cell phone and a second type RF communication link at said multimode cell phone different from said first type RF communication link according to claim **14**, wherein:

said second type RF communication link is a walkie-talkie link.

16. The apparatus for automatically switching between a first type RF communication link at a multimode cell phone and a second type RF communication link at said multimode cell phone different from said first type RF communication link according to claim **12**, wherein:

at least one of said RF communication links is a telephone call.

17. The apparatus for automatically switching between a first type RF communication link at a multimode cell phone and a second type RF communication link at said multimode cell phone different from said first type RF communication link according to claim **12**, wherein:

said first type RF communication link is a cell phone call.

18. The apparatus for automatically switching between a first type RF communication link at a multimode cell phone and a second type RF communication link at said multimode cell phone different from said first type RF communication link according to claim **17**, wherein:

said second type RF communication link is a cordless telephone call.

19. The apparatus for automatically switching between a first type RF communication link at a multimode cell phone and a second type RF communication link at said multimode cell phone different from said first type RF communication link according to claim **18**, wherein:

a cordless telephone used to participate in said cordless telephone call is adapted to implement a piconet protocol to communicate between a cordless telephone base unit and a matching remote handset.

* * * * *

Exhibit D

US007957450B2

(12) **United States Patent**
Hansen et al.

(10) **Patent No.: US 7,957,450 B2**
(45) **Date of Patent: Jun. 7, 2011**

(54) **METHOD AND SYSTEM FOR FRAME FORMATS FOR MIMO CHANNEL MEASUREMENT EXCHANGE**

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(73) Assignee: **Broadcom Corporation**

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **12/506,053**

(22) Filed: **Jul. 20, 2009**

(65) **Prior Publication Data**

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Related U.S. Application Data

(63) Continuation of application No. 11/052,353, filed on Feb. 7, 2005, now Pat. No. 7,564,914.

(60) Provisional application No. 60/636,255, filed on Dec. 14, 2004.

(51) **Int. Cl.**
H04B 1/00 (2006.01)

(52) **U.S. Cl.** **375/130**

(58) **Field of Classification Search** 375/267, 375/316, 340, 347, 349, 299; 370/338, 401; 455/101, 132, 296

See application file for complete search history.

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Syed Aon Mujtaba, IEEE 802.11 Wireless LANs TGn Sync Proposal Technical Specification, Jan. 18, 2005.

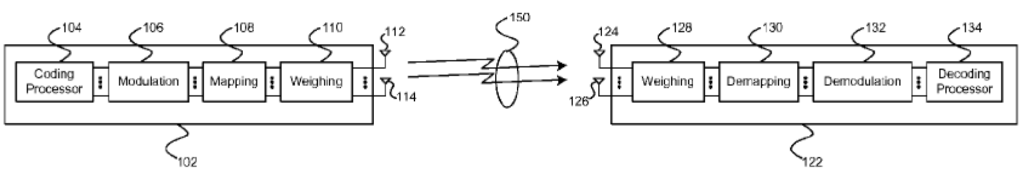
* cited by examiner

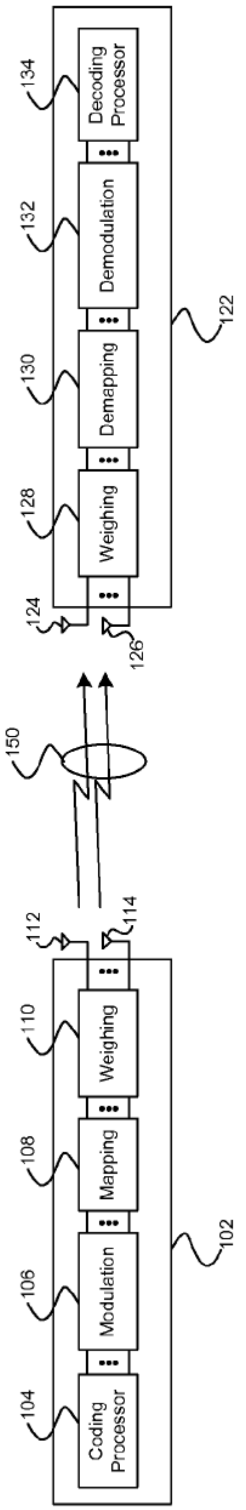
Primary Examiner — Khai Tran
(74) *Attorney, Agent, or Firm* — McAndrews, Held & Malloy, Ltd.

(57) **ABSTRACT**

A method and system for frame formats for MIMO channel measurement exchange is provided. Aspects of a method for communicating information in a communication system may comprise transmitting data via a plurality of radio frequency (RF) channels utilizing a plurality of transmitting antenna, receiving feedback information via at least one of a plurality of RF channels, and modifying a transmission mode based on the feedback information. Aspects of a method for communicating information in a communication system may also comprise receiving data via a plurality of receiving antenna, transmitting feedback information via at least one of the plurality of RF channels, and requesting modification of a transmission mode for the received data in transmitted response messages comprising the feedback information.

22 Claims, 9 Drawing Sheets





Coding Processor
Modulation
Mapping
Weighing
Weighing
Demapping
Demodulation
Decoding Processor
102
104
106
108
110
112
114
150
124
126
122
128
130
132
134

FIG. 1

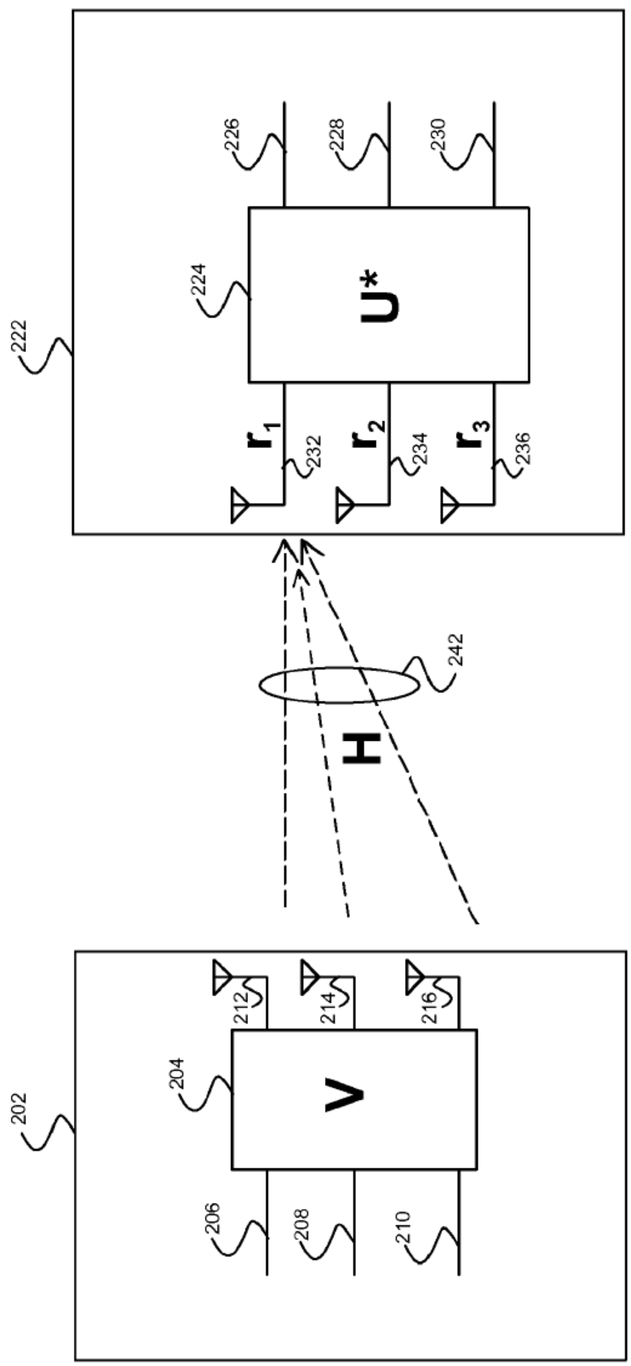

222
224
U*
226
228
230
r_1
r_2
r_3
232
234
236
H
242
202
204
V
206
208
210
212
214
216

FIG. 2

Case 3:18-cv-01786-CAB-BLM Document 87-6 Filed 05/24/19 PageID.3541 Page 140 of 150

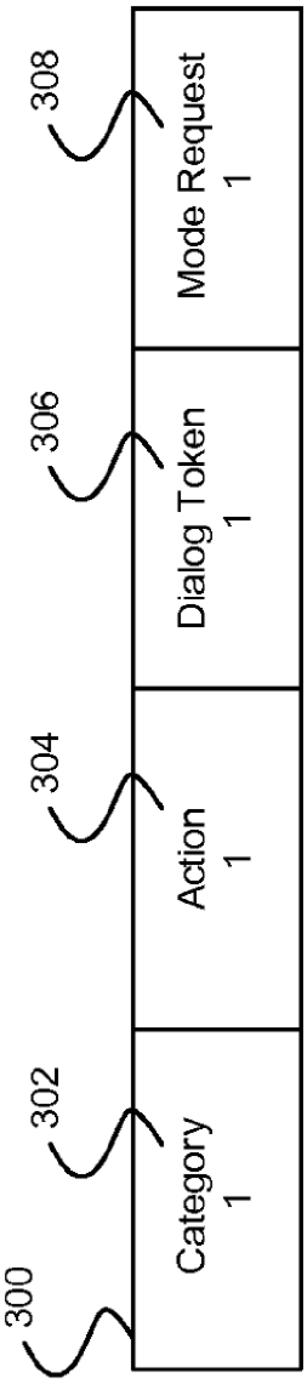


FIG. 3

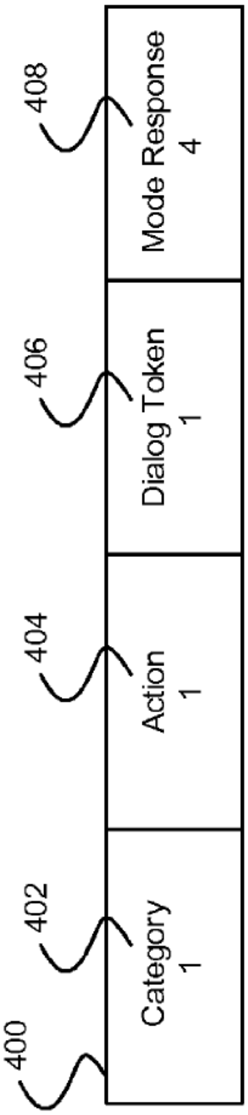

400
402
Category
1
404
Action
1
406
Dialog Token
1
408
Mode Response
4

FIG. 4

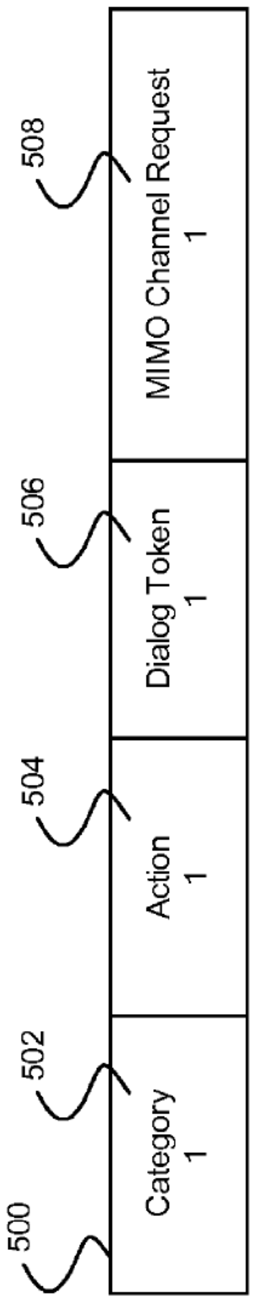

500
502
Category
1
504
Action
1
506
Dialog Token
1
508
MIMO Channel Request
1

FIG. 5

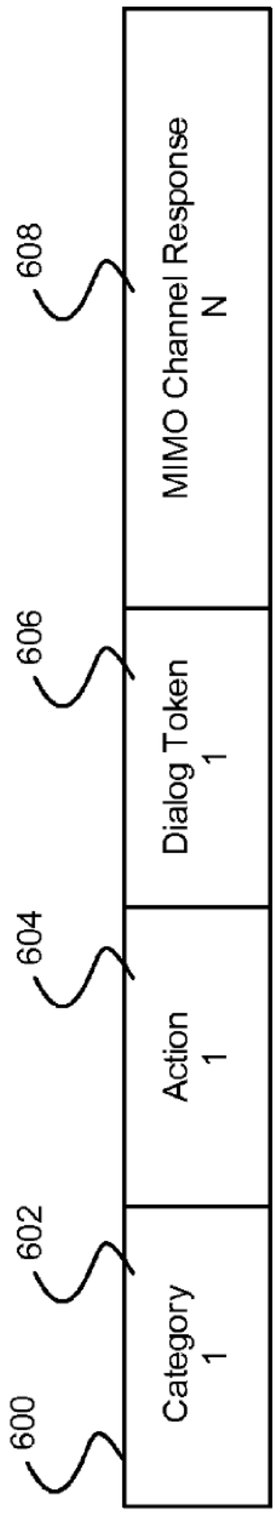

600
Category
1
602
Action
1
604
Dialog Token
1
606
MIMO Channel Response
N
608

FIG. 6a

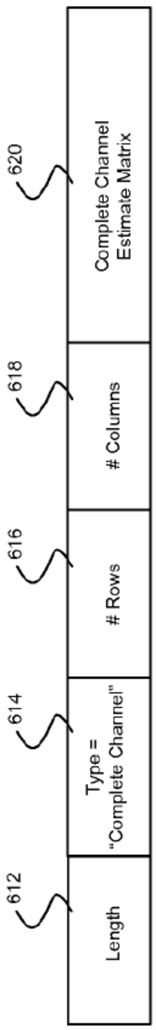


FIG. 6b

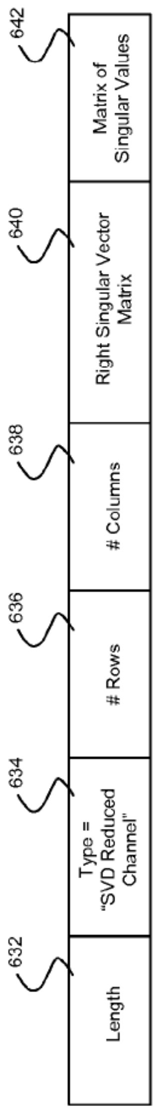


FIG. 6c

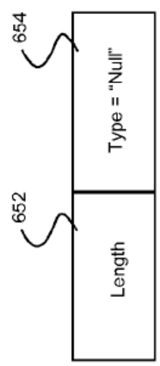


FIG. 6d

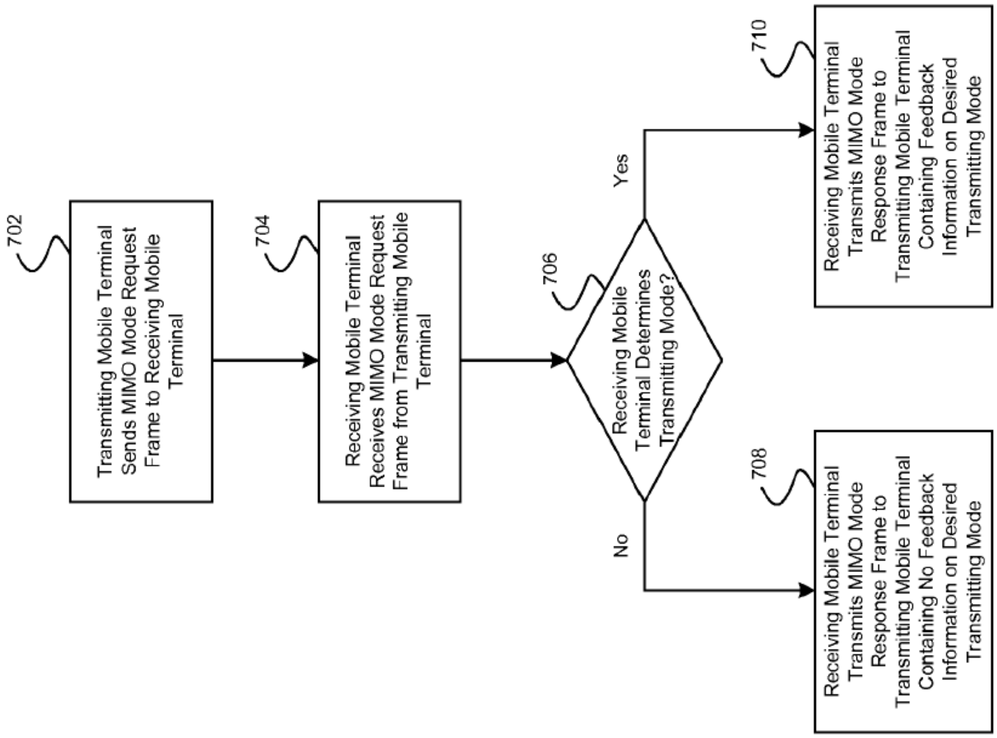

702
Transmitting Mobile Terminal Sends MIMO Mode Request Frame to Receiving Mobile Terminal
704
Receiving Mobile Terminal Receives MIMO Mode Request Frame from Transmitting Mobile Terminal
706
Receiving Mobile Terminal Determines Transmitting Mode?
Yes
No
708
Receiving Mobile Terminal Transmits MIMO Mode Response Frame to Transmitting Mobile Terminal Containing No Feedback Information on Desired Transmitting Mode
710
Receiving Mobile Terminal Transmits MIMO Mode Response Frame to Transmitting Mobile Terminal Containing Feedback Information on Desired Transmitting Mode

FIG. 7

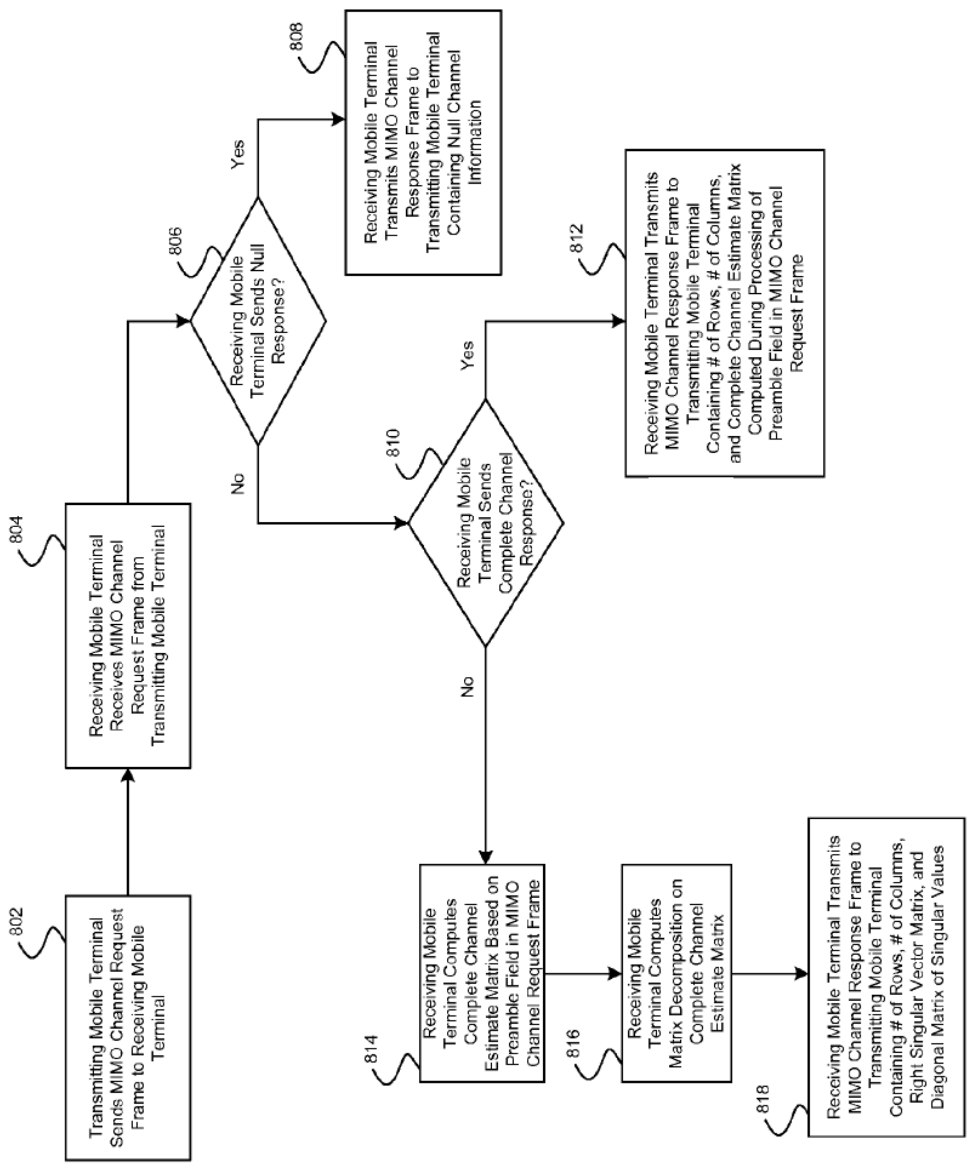

802
Transmitting Mobile Terminal Sends MIMO Channel Request Frame to Receiving Mobile Terminal
804
Receiving Mobile Terminal Receives MIMO Channel Request Frame from Transmitting Mobile Terminal
806
Receiving Mobile Terminal Sends Null Response?
Yes
No
808
Receiving Mobile Terminal Transmits MIMO Channel Response Frame to Transmitting Mobile Terminal Containing Null Channel Information
810
Receiving Mobile Terminal Sends Complete Channel Response?
Yes
No
812
Receiving Mobile Terminal Transmits MIMO Channel Response Frame to Transmitting Mobile Terminal Containing # of Rows, # of Columns, and Complete Channel Estimate Matrix Computed During Processing of Preamble Field in MIMO Channel Request Frame
814
Receiving Mobile Terminal Computes Complete Channel Estimate Matrix Based on Preamble Field in MIMO Channel Request Frame
816
Receiving Mobile Terminal Computes Matrix Decomposition on Complete Channel Estimate Matrix
818
Receiving Mobile Terminal Transmits MIMO Channel Response Frame to Transmitting Mobile Terminal Containing # of Rows, # of Columns, Right Singular Vector Matrix, and Diagonal Matrix of Singular Values

FIG. 8

METHOD AND SYSTEM FOR FRAME FORMATS FOR MIMO CHANNEL MEASUREMENT EXCHANGE

CROSS-REFERENCE TO RELATED APPLICATIONS/INCORPORATION BY REFERENCE

This application is a continuation of U.S. application Ser. No. 11/052,353 filed Feb. 7, 2005, which claims the benefit of 60/636,255 filed Dec. 14, 2004.

This application makes reference to:

U.S. patent application Ser. No. 11/052,389 filed Feb. 7, 2005.

All of the above stated applications are hereby incorporated herein in their entirety.

FIELD OF THE INVENTION

Certain embodiments of the invention relate to wireless networking. More specifically, certain embodiments of the invention relate to a method and system for frame formats for MIMO channel measurement exchange.

BACKGROUND OF THE INVENTION

The Institute for Electrical and Electronics Engineers (IEEE), in resolution IEEE 802.11, also referred as "802.11", has defined a plurality of specifications which are related to wireless networking. Among them are specifications for "closed loop" feedback mechanisms by which a receiving mobile terminal may feed back information to a transmitting mobile terminal to assist the transmitting mobile terminal in adapting signals which are sent to the receiving mobile terminal.

Smart antenna systems combine multiple antenna elements with a signal processing capability to optimize the pattern of transmitted signal radiation and/or reception in response to the communications medium environment. The process of optimizing the pattern of radiation is sometimes referred to as "beamforming," which may utilize linear array mathematical operations to increase the average signal to noise ratio (SNR) by focusing energy in desired directions. In conventional smart antenna systems, only the transmitter or the receiver may be equipped with more than one antenna, and may typically be located in the base transceiver station (BTS) where the cost and space associated with smart antenna systems have been perceived as more easily affordable than on mobile terminals such as cellular telephones. Such systems are also known as multiple input single output (MISO) when a multiple antenna transmitter is transmitting signals to a single antenna receiver, or single input multiple output (SIMO) when a multiple antenna receiver is receiving signals that have been transmitted from a single antenna transmitter. With advances in digital signal processing (DSP) integrated circuits (ICs) in recent years, multiple antenna multiple output (MIMO) systems have emerged in which mobile terminals incorporate smart antenna systems comprising multiple transmit antenna and multiple receive antenna. One area of early adoption of MIMO systems has been in the field of wireless networking, particularly as applied to wireless local area networks (WLANs) where transmitting mobile terminals communicate with receiving mobile terminals. IEEE resolution 802.11 comprises specifications for communications between mobile terminals in WLAN systems.

Signal fading is a significant problem in wireless communications systems, often leading to temporary loss of communications at mobile terminals. One of the most pervasive forms of fading is known as multipath fading, in which dispersion of transmitted signals due to incident reflections from buildings and other obstacles, results in multiple versions of the transmitted signals arriving at a receiving mobile terminal. The multiple versions of the transmitted signal may interfere with each other and may result in a reduced signal level detected at the receiving mobile terminal. When versions of the transmitted signal are 180° out of phase they may cancel each other such that a signal level of 0 is detected. Locations where this occurs may correspond to "dead zones" in which communication to the wireless terminal is temporarily lost. This type of fading is also known as "Rayleigh" or "flat" fading.

A transmitting mobile terminal may transmit data signals in which data is arranged as "symbols". The transmission of symbols may be constrained such that after a symbol is transmitted, a minimum period of time, T_s, must transpire before another symbol may be transmitted. After transmission of a symbol from a transmitting mobile terminal, some period of dispersion time, T_d, may transpire which may be the time over which the receiving mobile terminal is able to receive the symbol, including multipath reflections. The time T_d may not need to account for the arrival of all multipath reflections because interference from later arriving reflected signals may be negligible. If the period T_s is less than T_d there is a possibility that the receiving mobile terminal will start receiving a second symbol from the transmitting mobile terminal while it is still receiving the first symbol. This may result in intersymbol interference (ISI), producing distortion in received signals, and possibility resulting in a loss of information. The quantity $1/T_d$ is also referred to as the "coherence bandwidth" which may indicate the maximum rate at which symbols, and correspondingly information, may be transmitted via a given communications medium. One method to compensate for ISI in signals may entail utilizing DSP algorithms which perform adaptive equalization.

Another important type of fading is related to motion. When a transmitting mobile terminal, or a receiving mobile terminal is in motion, the Doppler phenomenon may affect the frequency of the received signal. The frequency of the received signal may be changed by an amount which is a function of the velocity at which a mobile terminal is moving. Because of the Doppler effect, ISI may result when a mobile terminal is in motion, particularly when the mobile terminal is moving at a high velocity. Intuitively, if a receiving mobile terminal is in motion and nearing a transmitting mobile terminal, the distance between the two mobile terminals will change as a function of time. As the distance is reduced, the propagation delay time, T_p, which is the time between when a transmitter first transmits a signal and when it first arrives at a receiver, is also reduced. As the mobile terminals become closer it is also possible that T_d may be increased if, for example, the transmitting mobile terminal does not reduce the radiated power of transmitted signals. If T_p becomes less than T_d, there may be ISI due to the Doppler effect. This case, which illustrates why data rates may be reduced for mobile terminals that are in motion, is referred to as "fast fading". Because fast fading may distort signals at some frequencies while not distorting signals at other frequencies, fast fading may also be referred to as "frequency selective" fading.

Smart antenna systems may transmit multiple versions of a signal in what is known as "spatial diversity". A key concept in spatial diversity is that the propagation of multiple versions of a signal, or "spatial stream", from different antenna may significantly reduce the probability of flat fading at the receiving mobile terminal since not all of the transmitted signals would have the same dead zone.

Current transmission schemes in MIMO systems typically fall into two categories: data rate maximization, and diversity maximization. Data rate maximization focuses on increasing the aggregate data transfer rate between a transmitting mobile terminal and a receiving mobile terminal by transmitting different spatial streams from different antenna. One method for increasing the data rate from a transmitting mobile terminal would be to decompose a high bit rate data stream into a plurality of lower bit rate data streams such that the aggregate bit rates among the plurality of lower bit rate data streams is equal to that of the high bit rate data stream. Next, each of the lower bit rate data streams may be mapped to at least one of the transmitting antenna for transmission. In addition, each signal comprising one of the lower bit rate data streams is multiplicatively scaled by a weighting factor prior to transmission. The plurality of multiplicative scale factors applied to the plurality of signals comprising the lower bit rate data streams may be utilized to form the transmitted "beam" in the beamforming technique. An example of a data rate maximization scheme is orthogonal frequency division multiplexing (OFDM), in which each of the plurality of signals is modulated by a different frequency carrier signal prior to mapping and multiplicative scaling. OFDM transmission may be resistant to multipath fading in that a portion, but most likely not all, of the data transmitted may be lost at any instant in time due to multipath fading.

Diversity maximization focuses on increasing the probability that a signal transmitted by a transmitting mobile terminal will be received at a receiving mobile terminal, and on increasing the SNR of received signals. In diversity maximization, multiple versions of the same signal may be transmitted by a plurality of antenna. The case in which a transmitting mobile terminal is transmitting the same signal via all of its transmitting antenna may be the pure spatial diversity case in which the aggregate data transfer rate may be equal to that of a single antenna mobile terminal. There is a plurality of hybrid adaptations of the data rate and spatial diversity maximization schemes which achieve varying data rates and spatial diversities.

MIMO systems employing beamforming may enable the simultaneous transmission of multiple signals occupying a shared frequency band, similar to what may be achieved in code division multiple access (CDMA) systems. For example, the multiplicative scaling of signals prior to transmission, and a similar multiplicative scaling of signals after reception, may enable a specific antenna at a receiving mobile terminal to receive a signal which had been transmitted by a specific antenna at the transmitting mobile terminal to the exclusion of signals which had been transmitted from other antenna. However, MIMO systems may not require the frequency spreading techniques used in CDMA transmission systems. Thus, MIMO systems may make more efficient utilization of frequency spectrum.

One of the challenges in beamforming is that the multiplicative scale factors which are applied to transmitted and received signals may be dependent upon the characteristics of the communications medium between the transmitting mobile terminal and the receiving mobile terminal. A communications medium, such as a radio frequency (RF) channel between a transmitting mobile terminal and a receiving mobile terminal, may be represented by a transfer system function, H. The relationship between a time varying transmitted signal, x(t), a time varying received signal, y(t), and the systems function may be represented as shown in equation [1]:

$$y(t)=H\times x(t)+n(t),\text{ where} \qquad \text{equation[1]}$$

n(t) represents noise which may be introduced as the signal travels through the communications medium and the receiver itself. In MIMO systems, the elements in equation[1] may be represented as vectors and matrices. If a transmitting mobile terminal comprises M transmitting antenna, and a receiving mobile terminal comprises N receiving antenna, then y(t) may be represented by a vector of dimensions Nx1, x(t) may be represented by a vector of dimensions Mx1, n(t) by a vector of dimensions Nx1, and H may be represented by a matrix of dimensions N×M. In the case of fast fading, the transfer function, H, may itself become time varying and may thus also become a function of time, H(t). Therefore, individual coefficients, $h_{ij}(t)$, in the transfer function H(t) may become time varying in nature.

In MIMO systems which communicate according to specifications in IEEE resolution 802.11, the receiving mobile terminal may compute H(t) each time a frame of information is received from a transmitting mobile terminal based upon the contents of a preamble field in each frame. The computations which are performed at the receiving mobile terminal may constitute an estimate of the "true" values of H(t) and may be known as "channel estimates". For a frequency selective channel there may be a set of H(t) coefficients for each tone that is transmitted via the RF channel. To the extent that H(t), which may be referred to as the "channel estimate matrix", changes with time and to the extent that the transmitting mobile terminal fails to adapt to those changes, information loss between the transmitting mobile terminal and the receiving mobile terminal may result.

Higher layer communications protocols, such as the transmission control protocol (TCP) may attempt to adapt to detected information losses, but such adaptations may be less than optimal and may result in slower information transfer rates. In the case of fast fading, the problem may actually reside at lower protocol layers, such as the physical (PHY) layer, and the media access control (MAC) layer. These protocol layers may be specified under IEEE 802.11 for WLAN systems. The method by which adaptations may be made at the PHY and MAC layers, however, may comprise a mechanism by which a receiving mobile terminal may provide feedback information to a transmitting mobile terminal based upon channel estimates which are computed at the receiving mobile terminal.

Existing closed loop receiver to transmitter mechanisms, also referred as "RX to TX feedback mechanisms", that exist under IEEE 802.11 include acknowledgement (ACK) frames, and transmit power control (TPC) requests and reports. The TPC mechanisms may allow a receiving mobile terminal to communicate information to a transmitting mobile terminal about the transmit power level that should be used, and the link margin at the receiving mobile terminal. The link margin may represent the amount of signal power that is being received, which is in excess of a minimum power required by the receiving mobile terminal to decode message information, or frames, that it receives.

A plurality of proposals is emerging for new feedback mechanisms as candidates for incorporation in IEEE resolution 802.11. Among the proposals for new feedback mechanisms are proposals from TGn (task group N) sync, which is a multi-industry group that is working to define proposals for next generation wireless networks which are to be submitted for inclusion in IEEE 802.11, and Qualcomm. The proposals may be based upon what may be referred as a "sounding frame". The sounding frame method may comprise the transmitting of a plurality of long training sequences (LTSs) that match the number of transmitting antenna at the receiving mobile terminal. The sounding frame method may not utilize beamforming or cyclic delay diversity (CDD). In the sounding frame method, each antenna may transmit independent information.

The receiving mobile terminal may estimate a complete reverse channel estimate matrix, H_{up}, for the channel defined in an uplink direction from the receiving mobile terminal to the transmitting mobile terminal. This may require calibration with the transmitting mobile terminal where the transmitting mobile terminal determines the forward channel estimate matrix, H_{down}, for the channel defined in a downlink direction from the transmitting mobile terminal to the receiving mobile terminal. To compensate for possible differences between H_{up} and H_{down} the receiving mobile terminal may be required to receive H_{down} from the transmitting mobile terminal, and to report $H_{up}-H_{down}$ as feedback information. The TGn sync proposal may not currently define a calibration response. A channel estimate matrix may utilize 24 or more bits for each channel and for each tone, comprising 12 or more bits in an in-phase (I) component and 12 or more bits in a quadrature (Q) component.

According to the principle of channel reciprocity, the characteristics of the RF channel in the direction from the transmitting mobile terminal to the receiving mobile terminal may be the same as the characteristics of the RF channel in the direction from the receiving mobile terminal to the transmitting mobile terminal $H_{up}=H_{down}$. In actual practice, however, there may be differences in the electronic circuitry between the respective transmitting mobile terminal and receiving mobile terminal such that, in some cases, there may not be channel reciprocity. This may require that a calibration process be performed in which H_{up} and H_{down} are compared to reconcile differences between the channel estimate matrices. However, there may be limitations inherent in some calibration processes. For example, some proposals for new IEEE 802.11 feedback mechanisms may be limited to performing "diagonal calibrations". These methods may not be able to account for conditions in which there are differences in non-diagonal coefficients between H_{up} and H_{down}. These non-diagonal coefficient differences may be the result of complicated antenna couplings at the respective transmitting mobile terminal and/or receiving mobile terminal. Accordingly, it may be very difficult for a calibration process to correct for these couplings. The ability of a calibration technique to accurately characterize the RF channel at any instant in time may be dependent upon a plurality of dynamic factors such as, for example, temperature variations. Another limitation of calibration procedures is that it is not known for how long a calibration renders an accurate characterization of the RF channel. Thus, the required frequency at which the calibration technique must be performed may not be known.

Further limitations and disadvantages of conventional and traditional approaches will become apparent to one of skill in the art, through comparison of such systems with some aspects of the present invention as set forth in the remainder of the present application with reference to the drawings.

BRIEF SUMMARY OF THE INVENTION

Certain embodiments of the invention may be found in a method and system for MIMO channel measurement exchange. Aspects of a method for communicating information in a communication system may comprise transmitting data via a plurality of radio frequency (RF) channels utilizing a plurality of transmitting antenna, receiving feedback information via at least one of the plurality of RF channels, and modifying a transmission mode based on the feedback information. Feedback information may be requested utilizing at least one of the plurality of transmitting antenna via at least one of the plurality of RF channels. The number of transmitting antenna utilized during the transmitting of data may be modified based on the feedback information. The transmission characteristics of data transmitted via at least one of the plurality of transmitting antenna may be modified based on the feedback information. Specific feedback information may be requested in request messages.

The method may further comprise negotiating a transmission mode for the transmitting of data via at least one of the plurality of RF channels. Aspects of the method may further comprise receiving feedback information comprising channel estimates based on the transmission characteristics of the data transmitted by at least one of the plurality of transmitting antenna. Feedback information may be derived from mathematical matrix decomposition of the channel estimates. Furthermore, feedback information may be derived from mathematical averaging of the result of mathematical matrix decomposition of the channel estimates. Feedback information may also be derived from a calibration of the channel estimates for communication in at least one direction via at least one of the plurality of RF channels.

In another embodiment of the invention a method for communicating information in a communication system may comprise receiving data via a plurality of RF channels utilizing a plurality of receiving antenna, transmitting feedback information via at least one of the plurality of RF channels, and requesting modification of the transmission mode for received data in transmitted response messages comprising the feedback information. Requests for feedback information may be received utilizing at least one of the plurality of receiving antenna via at least one of the plurality of RF channels. There may be requests for modification in the number of transmitting antenna utilized during transmission of received data in the transmitted response messages comprising the feedback information. There may be requests for modification in the transmission characteristics of data received via at least one of the plurality of receiving antenna in the transmitted response messages comprising the feedback information. The response messages may comprise the feedback information requested in the request messages.

The method may further comprise negotiating the transmission mode for the data received via at least one of the plurality of RF channels. Aspects of the method may further comprise transmitting feedback information comprising channel estimates based on the transmission characteristics of the data received via at least one of the plurality of receiving antenna. Feedback information may be derived from mathematical matrix decomposition of the channel estimates. Furthermore, feedback information may be derived from mathematical averaging of the result of mathematical matrix decomposition of the channel estimates. Feedback information may also be derived from a calibration of the channel estimates for communication in at least one direction via at least one of the plurality of RF channels.

Certain aspects of a system for communicating information in a communication system may comprise a transmitter that transmits data via a plurality of RF channels utilizing a plurality of transmitting antenna, with the transmitter receiving feedback information via at least one of the plurality of RF channels, and with the transmitter modifying a transmission mode based on the feedback information. The transmitter may request feedback information utilizing at least one of the plurality of transmitting antenna via at least one of the plurality of RF channels. The number of transmitting antenna utilized during the transmitting of data may be modified based on the feedback information. The transmission characteristics of data transmitted via at least one of the plurality of transmitting antenna may be modified based on the feedback information. The transmitter may request specific feedback information in request messages.

The system may further comprise the transmitter negotiating a transmission mode for the transmitting of data via at least one of the plurality of RF channels. Aspects of the system may further comprise receiving feedback information comprising channel estimates based on the transmission characteristics of the data transmitted by at least one of the plurality of transmitting antenna. Feedback information may be derived from mathematical matrix decomposition of the channel estimates. Furthermore, feedback information may be derived from mathematical averaging of the result of mathematical matrix decomposition of the channel estimates. Feedback information may also be derived from a calibration of the channel estimates for communication in at least one direction via at least one of the plurality of RF channels.

These and other advantages, aspects and novel features of the present invention, as well as details of an illustrated embodiment thereof, will be more fully understood from the following description and drawings.

BRIEF DESCRIPTION OF SEVERAL VIEWS OF THE DRAWINGS

FIG. **1** is an exemplary diagram illustrating wireless communication between two mobile terminals in accordance with an embodiment of the invention.

FIG. **2** is an exemplary diagram illustrating Eigen beamforming in accordance with an embodiment of the invention.

FIG. **3** is an exemplary diagram illustrating the MIMO mode request frame in accordance with an embodiment of the invention.

FIG. **4** is an exemplary diagram illustrating the MIMO mode response frame in accordance with an embodiment of the invention.

FIG. **5** is an exemplary diagram illustrating the MIMO channel request frame in accordance with an embodiment of the invention.

FIG. **6***a* is an exemplary diagram illustrating the MIMO channel response frame in accordance with an embodiment of the invention.

FIG. **6***b* is an exemplary diagram illustrating the MIMO channel response field for type="Complete Channel" in accordance with an embodiment of the invention.

FIG. **6***c* is an exemplary diagram illustrating the MIMO channel response field for type="SVD Reduced Channel" in accordance with an embodiment of the invention.

FIG. **6***d* is an exemplary diagram illustrating the MIMO channel response field for type="Null" in accordance with an embodiment of the invention.

FIG. **7** is an exemplary flowchart illustrating steps in the exchange of RX/TX feedback information utilizing MIMO mode request and MIMO mode response frames in accordance with an embodiment of the invention.

FIG. **8** is an exemplary flowchart illustrating steps in the exchange of RX/TX feedback information utilizing MIMO channel request and MIMO channel response frames in accordance with an embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

Certain embodiments of the invention may be found in a method and system for MIMO channel measurement exchange. There are options to conventional methods of RX/TX feedback mechanisms and to other proposals for new RX/TX feedback mechanisms. In one embodiment of the invention, a receiving mobile terminal may periodically transmit feedback information, comprising a channel estimate matrix, H_{up}, to a transmitting mobile terminal. In another embodiment of the invention, a receiving mobile terminal may perform a singular value decomposition (SVD) on the channel estimate matrix, and subsequently transmit SVD-derived feedback information to the transmitting mobile terminal. Utilizing SVD may increase the amount of computation required at the receiving mobile terminal but may reduce the quantity of information which is transmitted to the transmitting mobile terminal via the RF channel in comparison to transmitting the entire channel estimate matrix. Yet another embodiment of the invention may expand upon the method utilizing sounding frames to incorporate calibration. In this aspect of the invention, a receiving mobile terminal, after transmitting a sounding frame, may subsequently receive a channel estimate matrix, H_{down}, from the transmitting mobile terminal. The receiving mobile terminal may then transmit feedback information which is based upon the difference $H_{up}-H_{down}$, to the transmitting mobile terminal.

One embodiment of the invention may comprise a MIMO channel probe and response method, which may provide a flexible solution for RX/TX feedback because it may support a plurality of feedback mechanisms. In this regard, a transmitting mobile terminal may query a receiving mobile terminal to provide feedback information about the transmit mode configuration to use. The transmitting mobile terminal may receive feedback information comprising a full channel estimate matrix as computed by a receiving mobile terminal. Alternatively, the transmitting mobile terminal may receive feedback information comprising decomposition matrices that were derived from a full channel estimate matrix, or the transmitting mobile terminal may receive feedback information comprising matrices which contain averaged values derived from the decomposition matrices. Furthermore, the transmitting mobile terminal may receive feedback information which may be utilized in a calibration procedure.

RX/TX feedback mechanisms may be required to achieve high information transfer rates even in fast fading RF channels. In fast fading RF channels, however, the channel estimate matrix H(t) may change rapidly. Thus, the amount of feedback information that is required may also increase. Transmission of a large quantity of RT/TX feedback information may create excessive overhead on the RF channel and may reduce the available rate at which other information transfer may occur via the RF channel.

SVD is a method which may reduce the quantity of channel feedback information which is transmitted between a receiving mobile terminal and a transmitting mobile terminal. U.S. application Ser. No. 11/052,389 describes SVD and is hereby incorporated by reference herein in its entirety. When computing the SVD a plurality of techniques may be utilized in performing SVD reduction on the full channel estimate matrix. In one embodiment of the invention, a full channel estimate matrix which is computed by a receiving mobile terminal, H_{est}, may be represented by its SVD:

$$H_{est}=USV^H, \text{ where} \qquad \text{equation[2]}$$

H_{est} may be a complex matrix of dimensions $N_{rx}\times N_{tx}$, where N_{rx} may be equal to the number of receive antenna at the receiving mobile terminal, and N_{tx} may be equal to the number of transmit antenna at the transmitting mobile terminal, U may be an orthonormal complex matrix of dimensions N_{rx}-N_{rx}, S may be a diagonal real matrix of dimensions $N_{rx}\times N_{tx}$, and V may be an orthonormal complex matrix of dimensions $N_{tx}\times N_{tx}$ with V^H being the Hermitian transform of the matrix V. The singular values in the matrix S may represent the square roots of the Eigenvalues for the matrix H_{est}, U may represent the left singular vectors for the matrix H_{est} where the columns of U may be the Eigenvectors of the matrix product $H_{est}H_{est}^H$, and V^H may represent the right singular vectors for the matrix H_{est} where the columns of V may be the Eigenvectors of the matrix product $H_{est}^H H_{est}$.

If we define a square $N_{tx} \times N_{tx}$ matrix, $W = H_{est}^H H_{est}$, then for any given Eigenvalue of H_{est}, λ, the following relationship may exist for a nonzero vector, R:

$$WR = \lambda R \qquad \text{equation[3]}$$

From which it follows:

$$(H_{est}^H H_{est} - \lambda I)R = 0, \text{ where} \qquad \text{equation[4]}$$

I may be the identity matrix.

Solving equation[4], which may also be known as a "characteristic equation", may produce a set of Eigenvalues. By using each of these Eigenvalues iteratively in equation[4], a series of Eigenvectors, R, may be derived. The series of Eigenvectors, R, may form the columns of the matrix V.

Since $H_{est}^H H_{est} = VS^2V^H$, given a matrix of Eigenvectors, V, and a diagonal matrix of Eigenvalues, S, a matrix H_{est} may be derived. Therefore, the channel estimate matrix H_{est} from the SVD in equation[2] may be reconstructed by a transmitting mobile terminal from feedback information which contains V^H and S only. Since N_{rx} may be greater than N_{tx}, the quantity of information contained in matrices V^H and S may be less than that contained in the matrix H_{est}. In an embodiment of the invention, each of the complex coefficients of the V^H matrix may be encoded utilizing, for example, a signed 12-bit integer for an I component, and a signed 12-bit integer for a Q component. Each of the nonzero diagonal real coefficients of the S matrix may be encoded as, for example, IEEE 32-bit floating point numbers.

For an RF channel, H_{est} may be different for tones of different frequencies that are transmitted via the RF channel. Thus, a plurality of channel estimate matrices, H_{est}, may be computed to account for each tone which may be transmitted via the RF channel. In another embodiment of the invention, a further reduction in the quantity of information that is transmitted in feedback information may be achieved by computing a plurality of SVD on H_{est} as in equation[2], and averaging the coefficient values in matrices V^H and S over a plurality of tones. In one aspect of the invention, if M tones are transmitted via the RF channel, an adaptive modulation technique may be utilized, for example, and a diagonal matrix D derived based upon an average of the individual matrices S_i that are derived from each of the tones:

$$D = \frac{1}{M} \times \sum_{i=1}^{M} S_i \qquad \text{equation[5]}$$

Adaptive modulation may limit the representation of each nonzero coefficient in the diagonal matrix, d_{ii} to 8 bits per averaged tone. Thus by replacing the plurality of matrices S_i with the matrix D, the quantity of singular value matrix information which is transmitted in feedback information may be reduced by a factor of 4M.

A plurality of L matrices, $Avg_k(V^H)$, may be derived by averaging the coefficients from the matrices V^H in groups of 6 tones. Furthermore, the matrix of complex coefficient average values may be represented in the form:

$$Avg^k(V(f)^H) = |Avg^k(V(f)^H)|e^{j\phi}, \text{ where} \qquad \text{equation [6]}$$

$V(f)^H$ expresses V^H as a function of frequency, $|Avg^k(V(f)^H)|$ may represent the magnitude of the average of the I and Q components among the plurality of 6 $V(f)^H$ matrices whose coefficients are averaged in a group, and φ may represent the phase of the corresponding I and Q components, the index k may indicate an individual matrix of averaged values of V^H, and L may equal M/6. In an exemplary embodiment of the invention, the magnitude $|Avg^k(V(f)^H)|$ may be represented as a 6-bit integer, and the phase φ may be represented as a 4-bit integer. By replacing the plurality of M matrices, V^H, with a plurality of L matrices $Avg(V(f)^H)$, the quantity of singular vector information which is transmitted in feedback information may be reduced by a factor of $6 \times (24/10)$.

The invention is not limited to an average of singular values as expressed in equation[5] and the invention is not limited to expressing the average as an 8-bit binary data entity. Similarly, the invention as expressed in equation[6] is not limited to computing averages in groups of 6 tones, and the invention is not limited to expressing the magnitudes of the averages as 6-bit integers and the phases of the averages as 4-bit integers. Other possibilities exist and are contemplated as falling within the scope of the present invention.

In another embodiment of the invention, a calibration procedure may be performed between the transmitting mobile terminal and the receiving mobile terminal. In this case, the transmitting mobile terminal may compute a full channel estimate matrix, H_{down}. The transmitting mobile terminal may transmit H_{down} to the receiving mobile terminal. The receiving mobile terminal may then perform an SVD on H_{down} to derive matrices, S_{down}, and V_{down}^H based on the setting of U_{down} equal to the value of U that is derived from H_{est} in equation[2]. Furthermore, the receiving mobile terminal may derive D_{down} and $Avg^k(V_{down}(f)^H)$. The receiving mobile terminal may perform calibration by comparing the matrix D_{down} to the matrix D as derived in equation[5]:

$$D_\Delta = D_{down} - D \qquad \text{equation[7]}$$

and by comparing the plurality of matrices $Avg^k(V_{down}(f)^H)$ to the plurality of matrices $Avg^k(V(f)^H)$ as derived in equation [6]:

$$Avg^k(V_\Delta) = Avg^k(V_{down}(f)^H) - Avg^k(V(f)^H) \qquad \text{equation[8]}$$

If $Avg^k(V_\Delta)$ is equal to 0 for all values k=1, . . . L, then the SVD from equation[2] may be reconstructed at the transmitting mobile terminal by sending the matrix D_Δ only. If $Avg^k(V_\Delta)$ is not equal to 0 for all values k=1, . . . L, then the SVD from equation[2] may be reconstructed at the transmitting mobile terminal by sending the matrix D_Δ and the plurality of nonzero coefficients from the matrices $Avg^k(V_\Delta)$.

FIG. **1** is an exemplary diagram illustrating wireless communication between two mobile terminals in accordance with an embodiment of the invention. Referring to FIG. **1** there is shown a first mobile terminal **102**, a second mobile terminal **122** and a radio frequency (RF) communication channel **150**. An example of a standard method by which a first mobile terminal **102** and a second mobile terminal **122** may communicate via an RF channel **150** may be defined in IEEE resolution 802.11n. A plurality of different frequencies may be utilized to communicate via the RF channel **150** and one or more frequencies may be utilized to communicate information between the first mobile terminal **102** and a second mobile terminal **122**.

The first mobile terminal **102** may further comprise a coding processor **104**, a modulation block **106**, a mapping block **108**, a weighing block **110**, and one or more antenna such as the plurality of antenna **112**, . . . **114**. The second mobile terminal **122** may further comprise one or more antenna such as the plurality of antenna **124**, . . . **126**, a weighing block **128**, a demapping block **130**, a demodulation block **132**, and a decoding processor **134**.

The coding processor **104** may comprise suitable logic, circuitry and/or code that may be adapted to perform coding on information which is to be transmitted by the transmitting mobile terminal such as, for example, binary convolutional coding (BCC). The modulation block **106** may comprise suitable logic, circuitry and/or code that may be adapted to modulate baseband information into one or more RF signals. The mapping block **108** may comprise suitable logic, circuitry and/or code that may be adapted to assign an RF signal for transmission via one or more antenna **112**, . . . **114**. The weighing block **110** may comprise suitable logic, circuitry and/or code that may be adapted to assign scale factors, or weights, to individual RF signals for transmission via one or more antenna **112**, . . . **114**.

In the second mobile terminal **122**, one or more antenna **124**, . . . **126** may receive information from the first mobile terminal **102** via one or more frequencies over the RF communication channel **150**. The weighing block **128** may comprise suitable logic, circuitry and/or code that may be utilized to assign weights to individual RF signals received via one or more antenna **124**, . . . **126**. The demapping block **130** may comprise suitable logic, circuitry and/or code that may be utilized to reconcile a set of RF signals received from one or more antenna **124**, . . . **126** into another set of one or more RF signals. The demodulation block **132** may comprise suitable logic, circuitry and/or code that may be adapted to demodulate one or more RF signals into one or more baseband signals. The decoding processor **134** may comprise suitable logic, circuitry and/or code that may be adapted to perform decoding of information received from one or more antenna **124**, . . . **126** into, for example, binary information.

FIG. **2** is an exemplary diagram illustrating Eigen beamforming in accordance with an embodiment of the invention. Referring to FIG. **2** there is shown a transmitting mobile terminal **202**, a receiving mobile terminal **222**, and a plurality of RF channels **242**. The transmitting mobile terminal **202** comprises a transmit filter coefficient block V **204**, a first source signal s_1 **206**, a second source signal s_2 **208**, a third source signal s_3 **210**, and a plurality of transmitting antenna **212**, **214**, and **216**.

In operation, the transmitting antenna **212** may be adapted to transmit a signal x_1, the transmitting antenna **214** may transmit a signal x_2, and the transmitting antenna **216** may transmit a signal x_3. In beamforming each transmitted signal x_1, x_2, and x_3 may be a function of a weighted summation of at least one of the plurality of the source signals s_1, s_2, and s_3. The weights may be determined by the transmit filter coefficient block V such that:

$$X=VS, \text{ where} \qquad \text{equation[9]}$$

S may be represented by, for example, a 3×1 matrix $\{s_1, s_2, s_3\}$, and X may be represented by, for example, a 3×1 matrix $\{x_1, x_2, x_3\}$. Accordingly, V may be represented as a 3×3 matrix $\{\{v_{11},v_{12},v_{13}\}\{v_{21},v_{22},v_{23}\}\{v_{31},v_{32},v_{33}\}\}$.

The receiving mobile terminal **222** comprises a receive filter coefficient block U* **224**, a first destination signal $\tilde{y}_1$ **226**, a second destination signal $\tilde{y}_2$ **228**, a third destination signal $\tilde{y}_3$ **230**, and a plurality of receiving antenna **232**, **234**, and **236**. The receiving antenna **232** may be adapted to receive a signal y_1, the receiving antenna **234** may receive a signal y_2, and the receiving antenna **236** may receive a signal y_3. The characteristics of the plurality of RF channels **242** utilized for communication between the transmitting mobile terminal **202**, and the receiving mobile terminal **222** may be represented mathematically by a transfer coefficient matrix H.

FIG. **3** is an exemplary diagram illustrating the MIMO mode request frame in accordance with an embodiment of the invention. Referring to FIG. **3** there is shown a MIMO mode request frame **300**, which comprises a category field **302**, an action field **304**, a dialog token field **306**, and a mode request field **308**. The category field **302** may comprise 1 octet of binary data, for example, which may identify the general category of the frame within the wider context of all frames which are defined in IEEE 802.11. The category field **302** may be set to a specific value to identify the category which is defined for the MIMO mode request frame. The action field **304** may comprise 1 octet of binary data, for example, which may identify the frame type. The action field **304** may be set to a specific value to identify a MIMO mode request frame. The dialog token field **306** may comprise 1 octet of binary data, for example, which may identify a particular MIMO mode request frame. This field may be utilized to identify a specific MIMO mode request frame in the event that a transmitting mobile terminal **202** has transmitted a plurality of MIMO mode request frames, such as may be the case if a transmitting mobile terminal **202** were communicating with a plurality of receiving mobile terminals **222**.

The mode request field **308** may comprise 1 octet of binary data, for example, which may identify the function which is to be performed by the mobile terminal that receives the MIMO mode request frame. The mode request field **308** may be set to a specific value to indicate that feedback information about the transmit mode to be utilized when transmitting to a receiving mobile terminal **222** is being requested by the transmitting mobile terminal **202**. The mode request field **308** may also comprise information which indicates capabilities of the transmitting mobile terminal **202**. A receiving mobile terminal **222** that receives the MIMO mode request frame may use information about capabilities of the transmitting mobile terminal **202** in providing feedback information to the transmitting mobile terminal **202** in response to the MIMO mode request frame.

The MIMO mode request frame **300** may be transmitted by a transmitting mobile terminal **202** to a receiving mobile terminal **222** via an RF channel **242** to request that the receiving mobile terminal **222** provide feedback information about the transmit mode that the transmitting mobile terminal **202** should use when transmitting information to the receiving mobile terminal **222** via the RF channel **242**.

FIG. **4** is an exemplary diagram illustrating the MIMO mode response frame in accordance with an embodiment of the invention. Referring to FIG. **4** there is shown a MIMO mode response frame **400**, which comprises a category field **402**, an action field **404**, a dialog token field **406**, and a mode response field **408**. The category field **402** may comprise 1 octet of binary data, for example, which may identify the general category of the frame within the wider context of all frames which are defined in IEEE 802.11. The category field **402** may be set to a specific value to identify the category which is defined for the MIMO mode response frame. The action field **404** may comprise 1 octet of binary data, for example, which may identify the frame type. The action field **404** may be set to a specific value to identify a MIMO mode response frame. The dialog token field **406** may comprise 1 octet of binary data, for example, which may identify a particular MIMO mode response frame. This field may be utilized to identify a specific MIMO mode response frame to a transmitting mobile terminal **202**.

The mode response field **408** may comprise feedback information, which may be fed back in response to a previous MIMO mode request frame. The mode response field **408** may comprise 4 octets of binary data, for example. The mode response field **408** may comprise feedback information pertaining to a number of spatial streams that a transmitting mobile terminal **202** may utilize when transmitting to a receiving mobile terminal **222**, a number of transmit antenna that a transmitting mobile terminal **202** may utilize, and bandwidth that may be utilized by a transmitting mobile terminal **202**. In addition, the mode response field **408** may comprise feedback information about a code rate to use for information transmitted by a transmitting mobile terminal **202**, an error correcting code type to use, and a type of modulation to use for information transmitted by a transmitting mobile terminal **202** to a receiving mobile terminal **222**. A receiving mobile terminal **222** may indicate a null response in the mode request field **408** to indicate, for example, that the receiving mobile terminal **222** is unable to determine a requested transmit mode in response to a MIMO mode request frame **300**.

The MIMO mode response frame **400** may be transmitted by a receiving mobile terminal **222** to a transmitting mobile terminal **202** in response to a previous MIMO mode request frame **300** to provide feedback information about the transmit mode that the transmitting mobile terminal **202** should use when transmitting information to the receiving mobile terminal **222** via the RF channel **242**.

In an embodiment of the invention with reference to FIGS. **2-4**, the transmitting mobile terminal **202** may transmit a MIMO mode request frame **300** to a receiving mobile terminal **222**. In the MIMO mode request frame **300** an integer value, seq, may be contained in the dialog token field **306** of the MIMO mode request frame **300**. If the receiving mobile terminal **222** incorporates the value, seq, in the dialog token field **406** in the MIMO mode response frame **400**, the transmitting mobile terminal **202** which receives the MIMO mode response frame **400** may be able to identify the frame as being the response to the MIMO mode request frame **300** that had been sent previously by the transmitting mobile terminal **202** to the receiving mobile terminal **222**.

In another embodiment of the invention, the transmitting mobile terminal **202** may transmit a first MIMO mode request frame **300** to a first receiving mobile terminal **222**. The transmitting mobile terminal **202** may then transmit a second MIMO mode request frame to a second receiving mobile terminal. In the first MIMO mode request frame an integer value, seq1, may be contained in the dialog token field **306** of the MIMO mode request frame **300**. In the second MIMO mode request frame an integer value, seq2, may be contained in the dialog token field **306** of the MIMO mode request frame **300**. If the first receiving mobile terminal **222** incorporates the value, seq1, in the dialog token field **406** in the MIMO mode response frame **400**, the transmitting mobile terminal **202** which receives the MIMO mode response frame **400** may be able to identify the frame as being the response to the first MIMO mode request frame **300** that had been sent previously by the transmitting mobile terminal **202** to the first receiving mobile terminal **222**. If the second receiving mobile terminal **222** incorporates the value, seq2, in the dialog token field **406** in the MIMO mode response frame **400**, the transmitting mobile terminal **202** which receives the MIMO mode response frame **400** may be able to identify the frame as being the response that corresponds to the second MIMO mode request frame **300** that had been sent previously by the transmitting mobile terminal **202** to the second receiving mobile terminal.

Any individual field in either the MIMO mode request frame **300** or the MIMO mode response frame **400** may comprise a plurality of octets of binary data. The MIMO mode request frame **300**, the MIMO mode response frame **400**, and any individual field in either the MIMO mode request frame **300** or the MIMO mode response frame **400** may be of variable length. The MIMO mode request frame **300** or the MIMO mode response frame **400** may comprise information which indicates the length of the respective frame. The MIMO mode request frame **300** or the MIMO mode response frame **400** may comprise information which indicates the length of any fields contained within the respective frame. The MIMO mode request frame **300** and the MIMO mode response frame **400** may comprise other information which enable a receiving mobile terminal **222** and a transmitting mobile terminal **202** to negotiate a transmission mode for a common RF channel.

FIG. **5** is an exemplary diagram illustrating the MIMO channel request frame in accordance with an embodiment of the invention. Referring to FIG. **5** there is shown a MIMO channel request frame **500**, which comprises a category field **502**, an action field **504**, a dialog token field **506**, and a MIMO channel request field **508**. The category field **502** may comprise 1 octet of binary data, for example, which may identify the general category of the frame within the wider context of all frames which are defined in IEEE 802.11. The category field **502** may be set to a specific value to identify the category which is defined for the MIMO channel request frame. The action field **504** may comprise 1 octet of binary data, for example, which may identify the frame type. The action field **504** may be set to a specific value to identify a MIMO channel request frame. The dialog token field **506** may comprise 1 octet of binary data, for example, which may identify a particular MIMO channel request frame. This field may be utilized to identify a specific MIMO channel request frame in the event that a transmitting mobile terminal **202** has transmitted a plurality of MIMO channel request frames, such as may be the case if a transmitting mobile terminal **202** were communicating with a plurality of receiving mobile terminals **222**.

The MIMO channel request frame **500** may be transmitted by a transmitting mobile terminal **202** to a receiving mobile terminal **222** via an RF channel **242** to request that the receiving mobile terminal **222** provide feedback information about the channel estimates that the receiving mobile terminal **222** has computed for the RF channel **242**.

The MIMO channel request field **508** may comprise 1 octet of binary data, for example, which may identify the function which is to be performed by the mobile terminal that receives the MIMO channel request frame. The channel request field **508** may be set to a specific value to indicate that feedback information about the channel estimates that the receiving mobile terminal **222** has computed for the RF channel **242** is being requested by the transmitting mobile terminal **202**. The MIMO channel request field **508** may also comprise information from the channel estimation matrix, H_{down}, which is computed at the transmitting mobile terminal **202**. A receiving mobile terminal **222** that receives the MIMO channel request frame may use H_{down} information from the transmitting mobile terminal **202** to perform calibration.

FIG. **6a** is an exemplary diagram illustrating the MIMO channel response frame in accordance with an embodiment of the invention. Referring to FIG. **6a** there is shown a MIMO channel response frame **600**, which comprises a category field **602**, an action field **604**, a dialog token field **606**, and a MIMO channel response field **608**. The category field **602** may comprise 1 octet of binary data, for example, which may identify the general category of the frame within the wider context of all frames which are defined in IEEE 802.11. The category field **602** may be set to a specific value to identify the category which is defined for the MIMO channel response frame. The action field **604** may comprise 1 octet of binary data, for example, which may identify the frame type. The action field **604** may be set to a specific value to identify a MIMO channel response frame. The dialog token field **606** may comprise 1 octet of binary data, for example, which may identify a particular MIMO channel response frame. This field may be utilized to identify a specific MIMO channel response frame to a transmitting mobile terminal **202**.

The MIMO channel response field **608** may comprise a variable number of octets of binary data, for example, which may comprise feedback information in response to a previous MIMO channel request frame. FIG. **6***b* is an exemplary diagram illustrating the MIMO channel response field for type="complete channel" in accordance with an embodiment of the invention. The length subfield **612** within the MIMO channel response field **608** may comprise 2 octets of binary data, for example, which may comprise information which indicates the length of the MIMO channel response field **608**. The type subfield **614** within the MIMO channel response field may comprise 1 octet of binary data, for example, which may comprise information that indicates the feedback information which is contained the MIMO channel response field **608**. In FIG. **6***b* the feedback information type is shown to indicate "complete channel". Subfield **616** within the MIMO channel response field **608** may comprise 1 octet of binary data, for example, which may comprise an indication of the number of rows in the matrix of feedback information which is contained in the MIMO channel response field **608**. Subfield **618** within the MIMO channel response field **608** may comprise 1 octet of binary data, for example, which may comprise an indication of the number of columns in the matrix of feedback information which is contained in the MIMO channel response field **608**. Subfield **620** within the MIMO channel response field **608** may comprise a variable number of octets based upon the contents of subfields **616** and **618**, for example, which may comprise the complete channel estimate matrix which was computed during processing of the preceding MIMO channel request frame **500**.

FIG. **6***c* is an exemplary diagram illustrating the MIMO channel response field for type="SVD Reduced Channel" in accordance with an embodiment of the invention. The length subfield **632** within the MIMO channel response field **608** may comprise 2 octets of binary data, for example, which may comprise information which indicates the length of the MIMO channel response field **608**. The type subfield **634** within the MIMO channel response field may comprise 1 octet of binary data, for example, which may comprise information that indicates the feedback information which is contained the MIMO channel response field **608**. In FIG. **6***c* the feedback information type is shown to indicate "SVD reduced channel". Subfield **636** within the MIMO channel response field **608** may comprise 1 octet of binary data, for example, which may comprise an indication of the number of rows in the matrix of feedback information which is contained in the MIMO channel response field **608**. Subfield **638** within the MIMO channel response field **608** may comprise 1 octet of binary data, for example, which may comprise an indication of the number of columns in the matrix of feedback information which is contained in the MIMO channel response field **608**. Subfield **640** within the MIMO channel response field **608** may comprise a variable number of octets based upon the contents of subfields **636** and **638**, for example, which may comprise the right singular vector matrix, V. Subfield **642** within the MIMO channel response field **608** may comprise a variable number of octets based upon the contents of subfields **636** and **638**, for example, which may comprise the diagonal matrix of singular values, S. The matrices V and S may be derived from the complete channel estimate matrix which was computed during the processing of the preceding MIMO channel request frame **500**.

FIG. **6***d* is an exemplary diagram illustrating the MIMO channel response field for type="Null" in accordance with an embodiment of the invention. The length subfield **652** within the MIMO channel response field **608** may comprise 2 octets of binary data, for example, which may comprise information which indicates the length of the MIMO channel response field **608**. The type subfield **654** within the MIMO channel response field may comprise 1 octet of binary data, for example, which may comprise information that indicates the feedback information which is contained the MIMO channel response field **608**. In FIG. **6***d* the feedback information type is shown to indicate "Null". If the feedback information type is "null", the receiving mobile terminal **222** may not have been able to compute a channel estimate, in which case the MIMO channel response field **608** may not comprise feedback information.

The MIMO channel response frame **600** may be transmitted by a receiving mobile terminal **222** to a transmitting mobile terminal **202** in response to a previous MIMO channel request frame **500** to provide feedback information about the channel estimates that the receiving mobile terminal **222** has computed for the RF channel **242**.

If the quantity of data from SVD derived matrices are further reduced by averaging, the MIMO channel response field **608** may comprise an indication of the number of rows in the matrices which are contained in the MIMO channel response field **608**, an indication of the number of columns in the matrices which are contained in the MIMO channel response field, the matrix D as derived in equation[5], and the plurality of matrices $Avg^k(V(f)^H)$ as derived in equation[6]. If the calibration procedure is used, the MIMO channel response field **608** may comprise an indication of the number of rows in the matrices which are contained in the MIMO channel response field **608**, an indication of the number of columns in the matrices which are contained in the MIMO channel response field **608**, the matrix D_Δ as derived in equation[7], and the matrix $Avg^k(V_\Delta)$ as derived in equation[8].

The initial MIMO channel request frame **500** may be sent by the transmitting mobile terminal **202** to the receiving mobile terminal **222** without beamforming, and utilizing a number of spatial streams may equal the number of antenna. For each spatial stream, the lowest data rate may be used when transmitting the MIMO channel request frame **500** to enable the transfer of information between the transmitting mobile terminal **202** and receiving mobile terminal **222** to be as robust as possible. For example, with reference to FIG. **2**, without beamforming antenna **212** may transmit a signal which is proportional to signal s_1 **206** only, while antenna **214** may transmit a signal which is proportional to signal s_2 **208** only, and antenna **216** may transmit a signal which is proportional to signal s_3 **210** only such that:

$$X=cS, \text{ where} \qquad \text{equation[10]}$$

S may be represented by a 3×1 matrix $\{s_1, s_2, s_3\}$, X may be represented by a 3×1 matrix $\{x_1, x_2, x_3\}$, and c may be a scalar entity.

Any individual field in either the MIMO channel request frame **500** or the MIMO channel response frame **600** may comprise a plurality of octets of binary data. The MIMO channel request frame **500**, the MIMO channel response frame **600**, and any individual field in either the MIMO channel request frame **500** or the MIMO channel response frame **600** may be of variable length. The MIMO channel request frame **500** or the MIMO channel response frame **600** may comprise information which indicates the length of the respective frame. The MIMO channel request frame **500** or the MIMO channel response frame **600** may comprise information which indicates the length of any fields contained within the respective frame. The MIMO channel request frame **500** and the MIMO channel response frame **600** may comprise other information which enable a receiving mobile terminal **222** to communicate feedback information about the channel estimates that the receiving mobile terminal **222** has computed for the RF channel **242** to a transmitting mobile terminal **202**.

FIG. **7** is an exemplary flowchart illustrating steps in the exchange of RX/TX feedback information utilizing MIMO mode request and MIMO mode response frames in accordance with an embodiment of the invention. Referring to FIG. **7**, in step **702** a transmitting mobile terminal **202** may send a MIMO mode request frame to a receiving mobile terminal **222**. In step **704** the receiving mobile terminal **222** may receive the MIMO mode request frame from the transmitting mobile terminal **202**. In step **706** the receiving mobile terminal **222** may determine the transmitting mode. If the receiving mobile terminal **222** determines the transmitting mode, in step **710**, the receiving mobile terminal **222** may transmit a MIMO mode response frame to the transmitting mobile terminal **202** containing information about the desired transmitting mode. If the receiving mobile terminal **222** does not determine the transmitting mode, in step **708**, the receiving mobile terminal **222** may transmit a MIMO mode response frame to the transmitting mobile terminal **202** which contains no feedback information on the desired transmitting mode.

FIG. **8** is an exemplary flowchart illustrating steps in the exchange of RX/TX feedback information utilizing MIMO channel request and MIMO channel response frames in accordance with an embodiment of the invention. Referring to FIG. **8**, in step **802** a transmitting mobile terminal **202** may send a MIMO channel request frame to a receiving mobile terminal **222**. In step **804** the receiving mobile terminal **222** may receive the MIMO channel request frame from the transmitting mobile terminal **202**. In step **806** the receiving mobile terminal **222** may determine whether a null response is to be returned to the transmitting mobile terminal **202**. If a null response is to be returned, in step **808**, the receiving mobile terminal **222** may transmit a MIMO channel response frame to the transmitting mobile terminal **202** containing null channel information.

If a null response is not to be sent, in step **810** the receiving mobile terminal may determine whether to send a complete channel response. If a complete channel response is to be sent, in step **812** the receiving mobile terminal **222** may transmit a MIMO channel response frame to the transmitting mobile terminal **202** containing the number of transmit antenna, the number of receive antenna, and a complete channel estimate matrix computed during the processing of the preamble field in the preceding MIMO channel request frame.

If a complete channel response is not to be sent, in step **814**, the receiving mobile terminal **222** may compute a complete channel estimate matrix based on the preamble field in the preceding MIMO channel request frame. In step **816**, the receiving mobile terminal **222** may compute the matrix decomposition on the complete channel estimate matrix. In step **816**, matrix decomposition on the complete channel estimate matrix may be performed by a plurality of methods comprising SVD, QR decomposition, lower diagonal, diagonal, upper diagonal (LDU) decomposition, and Cholesky decomposition. In step **818**, the receiving mobile terminal **222** may transmit a MIMO channel response frame to the transmitting mobile terminal **202** containing the number of transmit antenna, the number of receive antenna, the right singular vector matrix, and the diagonal matrix of singular values.

The channel feedback method may enable more precise estimation of RF channel characteristics than is possible with conventional IEEE 802.11 systems, or when utilizing other proposals for new RX/TX feedback mechanisms. In conventional IEEE 802.11 specifications, there may be no feedback mechanism by which the receiving mobile terminal **222** may indicate a specific transmitting mode to be utilized by a transmitting mobile terminal **202**. Consequently, in conventional systems based upon IEEE 802.11, the transmitting mobile terminal **202** may independently select a transmitting mode with no mechanism by which the transmitting mode may be adapted to the requirements of the receiving mobile terminal **222**. The MIMO mode response mechanism may enable a receiving mobile terminal **222** to suggest a particular transmitting mode to the transmitting mobile terminal **202**.

The channel feedback method described may enable the receiving mobile terminal **222** to efficiently communicate feedback information, to the transmitting mobile terminal **202**, about the characteristics of the RF channel **242** as detected at the receiving mobile terminal **222**. In response, the transmitting mobile terminal **202** may adapt the RF signals that are transmitted to the receiving mobile terminal **222** based upon the channel feedback information received from the receiving mobile terminal **222**. Embodiments of the invention which have been described may minimize the quantity of feedback information and thereby reduce the amount of overhead imposed on the RF channel as a result of RX/TX feedback. This may enable the channel feedback mechanism to be utilized effectively in fast fading RF channels. As a result, the channel feedback method may enable the transmitting mobile terminal to achieve higher information transfer rates, and more effective beamforming on signals that are transmitted to the receiving mobile terminal via an RF channel.

The invention may not be limited to the SVD method to reduce the amount of feedback information which is sent via an RF channel. A plurality of methods may be utilized for reducing the quantity of feedback information when compared to the amount of information that is contained in a full channel estimate matrix. These methods may comprise, for example, SVD, LDU decomposition, Eigenvalue decomposition, QR decomposition, and Cholesky decomposition.

Accordingly, the present invention may be realized in hardware, software, or a combination of hardware and software. The present invention may be realized in a centralized fashion in at least one computer system, or in a distributed fashion where different elements are spread across several interconnected computer systems. Any kind of computer system or other apparatus adapted for carrying out the methods described herein is suited. A typical combination of hardware and software may be a general-purpose computer system with a computer program that, when being loaded and executed, controls the computer system such that it carries out the methods described herein.

The present invention may also be embedded in a computer program product, which comprises all the features enabling the implementation of the methods described herein, and which when loaded in a computer system is able to carry out these methods. Computer program in the present context means any expression, in any language, code or notation, of a set of instructions intended to cause a system having an information processing capability to perform a particular function either directly or after either or both of the following: a) conversion to another language, code or notation; b) reproduction in a different material form.

While the present invention has been described with reference to certain embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted without departing from the scope of the present invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the present invention without departing from its scope. Therefore, it is intended that the present invention not be limited to the particular embodiment disclosed, but that the present invention will include all embodiments falling within the scope of the appended claims.

What is claimed is:

1. A method for communication, the method comprising:

computing a plurality of channel estimate matrices based on signals received by a mobile terminal from a base station, via one or more downlink RF channels, wherein said plurality of channel estimate matrices comprise coefficients derived from performing a singular value matrix decomposition (SVD) on said received signals; and

transmitting said coefficients as feedback information to said base station, via one or more uplink RF channels.

2. The method according to claim **1**, comprising computing each of said plurality of channel estimate matrices for a corresponding one of a plurality of tones, wherein each of said plurality of tones corresponds to one or more distinct frequencies.

3. The method according to claim **2**, comprising computing one or both of, a right singular vector matrix and a singular value matrix, corresponding to each of said plurality of channel estimate matrices.

4. The method according to claim **3**, comprising computing an average singular value matrix based on an average of a plurality of said computed singular value matrices, wherein said average of said plurality of said computed singular value matrices is computed based on said plurality of tones.

5. The method according to claim **4**, comprising communicating said computed average singular value matrix via said transmitted feedback information.

6. The method according to claim **5**, wherein said computed average singular value matrix comprises a matrix rank, which is equal to the number of nonzero singular values in said computed average singular value matrix.

7. The method according to claim **6**, wherein each of said nonzero singular values in said computed average singular value matrix comprises a determined number of bits.

8. The method according to claim **3**, comprising computing said coefficients based on an average of a plurality of said computed right singular vector matrices, wherein each of said coefficients is computed based on a corresponding distinct at least a portion of said plurality of tones.

9. The method according to claim **8**, wherein each value in said coefficients comprises a corresponding magnitude value and phase value.

10. The method according to claim **9**, wherein each of said corresponding magnitude value comprises a determined number of bits, and each of said corresponding phase value comprises a separately determined number of bits.

11. A system for communication, the system comprising:

one or more circuits of a mobile terminal that are operable to compute a plurality of channel estimate matrices based on signals received by said mobile terminal from a base station, via one or more downlink RF channels, wherein said plurality of channel estimate matrices comprise coefficients derived from performing a singular value matrix decomposition (SVD) on said received signals; and

said one or more circuits are operable to transmit said coefficients as feedback information to said base station, via one or more uplink RF channels.

12. The system according to claim **11**, wherein said one or more circuits are operable to compute each of said plurality of channel estimate matrices for a corresponding one of a plurality of tones, wherein each of said plurality of tones corresponds to one or more distinct frequencies.

13. The system according to claim **12**, wherein said one or more circuits are operable to compute one or both of, a right singular vector matrix and a singular value matrix, corresponding to each of said plurality of channel estimate matrices.

14. The system according to claim **13**, wherein said one or more circuits are operable to compute an average singular value matrix based on an average of a plurality of said computed singular value matrices, wherein said average of said plurality of said computed singular value matrices is computed based on said plurality of tones.

15. The system according to claim **14**, wherein said one or more circuits are operable to communicate said computed average singular value matrix via said transmitted feedback information.

16. The system according to claim **15**, wherein said computed average singular value matrix comprises a matrix rank, which is equal to the number of nonzero singular values in said computed average singular value matrix.

17. The system according to claim **16**, wherein each of said nonzero singular values in said computed average singular value matrix comprises a determined number of bits.

18. The system according to claim **13**, wherein said one or more circuits are operable to compute said coefficients based on an average of a plurality of said computed right singular vector matrices, wherein each of said coefficients is computed based on a corresponding distinct at least a portion of said plurality of tones.

19. The system according to claim **18**, wherein each value in said coefficients comprises a corresponding magnitude value and phase value.

20. The system according to claim **19**, wherein each of said corresponding magnitude value comprises a determined number of bits, and each of said corresponding phase value comprises a separately determined number of bits.

21. A method for communication, the method comprising:

computing a plurality of channel estimates based on signals received by a mobile terminal from a base station, via one or more downlink RF channels;

deriving a matrix based on the plurality of channel estimates, wherein the matrix comprises coefficients from performing a singular value matrix decomposition (SVD) on said plurality of channel estimates; and

transmitting the coefficients as feedback information to said base station, via one or more uplink RF channels.

22. A system for communication, the system comprising:

one or more circuits of a mobile terminal that are operable to compute a plurality of channel estimates based on signals received by said mobile terminal from a base station, via one or more downlink RF channels;

said one or more circuits are operable to derive a matrix based on said plurality of channel estimates, wherein said matrix comprises coefficients derived from performing a singular value matrix decomposition (SVD) on said plurality of channel estimates; and

said one or more circuits are operable to transmit said coefficients as feedback information to said base station, via one or more uplink RF channels.

* * * * *

Exhibit E

US008416862B2

(12) United States Patent
Aldana et al.

(10) Patent No.: US 8,416,862 B2
(45) Date of Patent: Apr. 9, 2013

(54) **EFFICIENT FEEDBACK OF CHANNEL INFORMATION IN A CLOSED LOOP BEAMFORMING WIRELESS COMMUNICATION SYSTEM**

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(73) Assignee: **Broadcom Corporation**, Irvine, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 2247 days.

(21) Appl. No.: **11/237,341**

(22) Filed: **Sep. 28, 2005**

(65) **Prior Publication Data**

US 2006/0239374 A1 Oct. 26, 2006

Related U.S. Application Data

(63) Continuation-in-part of application No. 11/168,793, filed on Jun. 28, 2005.

(60) Provisional application No. 60/673,451, filed on Apr. 21, 2005, provisional application No. 60/698,686, filed on Jul. 13, 2005.

(51) **Int. Cl.**
H04K 1/10 (2006.01)

(52) **U.S. Cl.** **375/260**; 375/267; 375/350

(58) **Field of Classification Search** 375/267
See application file for complete search history.

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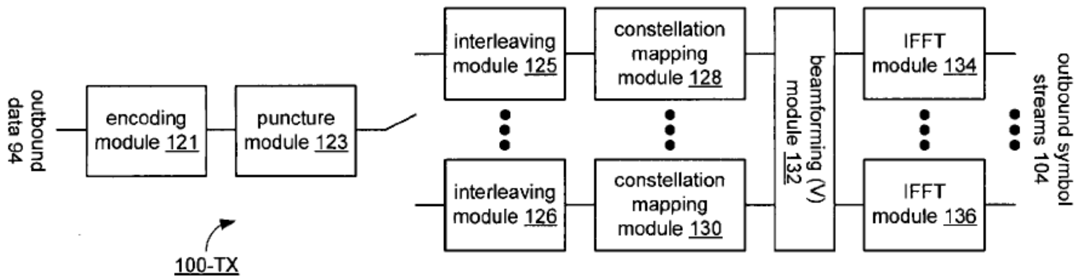
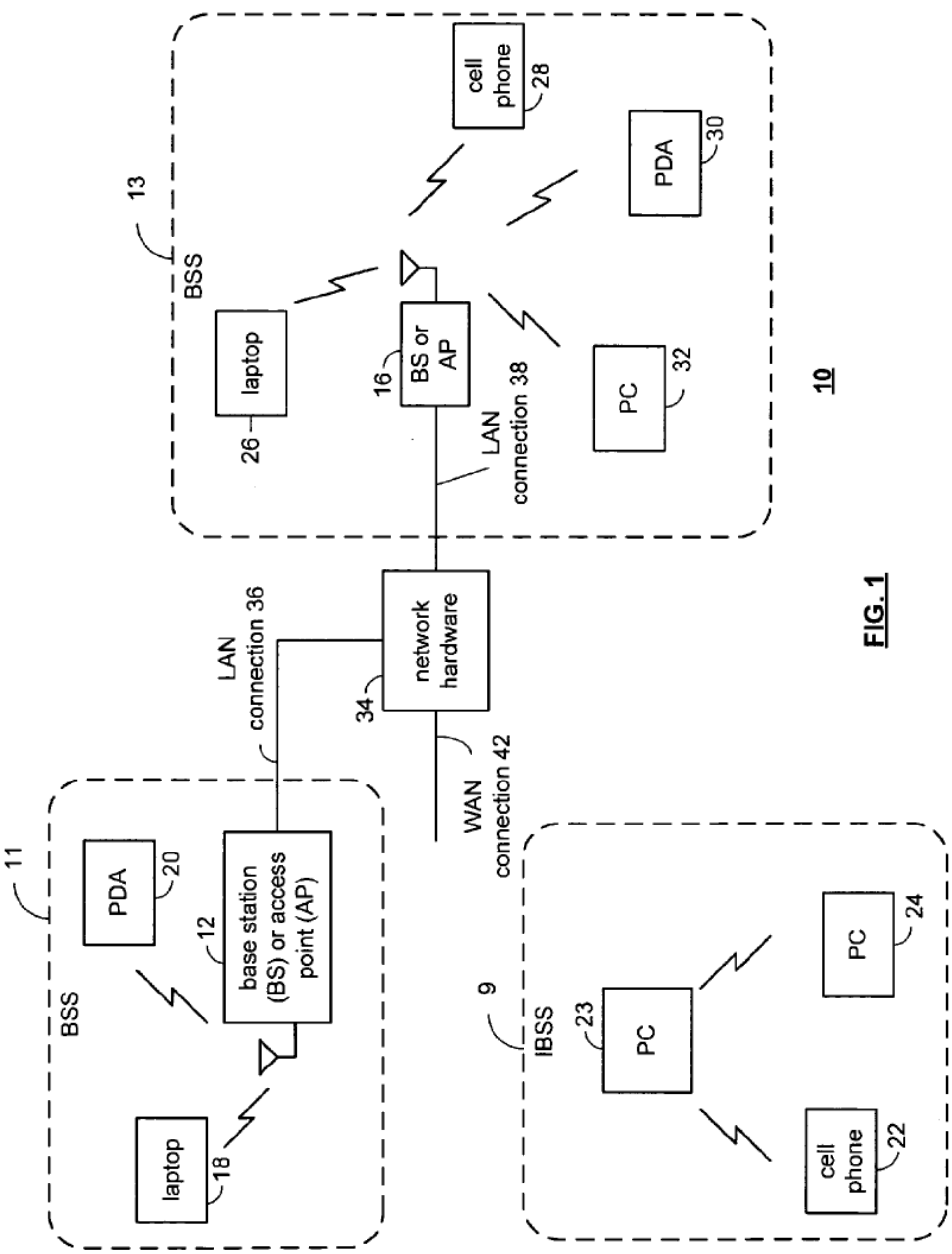
Primary Examiner — Shuwang Liu
Assistant Examiner — Michael Neff
(74) *Attorney, Agent, or Firm* — Garlick & Markison; Holly L. Rudnick

(57) **ABSTRACT**

A method for feeding back transmitter beamforming information from a receiving wireless communication device to a transmitting wireless communication device includes a receiving wireless communication device receiving a preamble sequence from the transmitting wireless device. The receiving wireless device estimates a channel response based upon the preamble sequence and then determines an estimated transmitter beamforming unitary matrix based upon the channel response and a receiver beamforming unitary matrix. The receiving wireless device then decomposes the estimated transmitter beamforming unitary matrix to produce the transmitter beamforming information and then wirelessly sends the transmitter beamforming information to the transmitting wireless device. The receiving wireless device may transform the estimated transmitter beamforming unitary matrix using a QR decomposition operation such as a Givens Rotation operation to produce the transformer beamforming information.

20 Claims, 8 Drawing Sheets




13
BSS
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cell phone
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PDA
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PC
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LAN connection 38
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WAN connection 42
11
BSS
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PC
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cell phone
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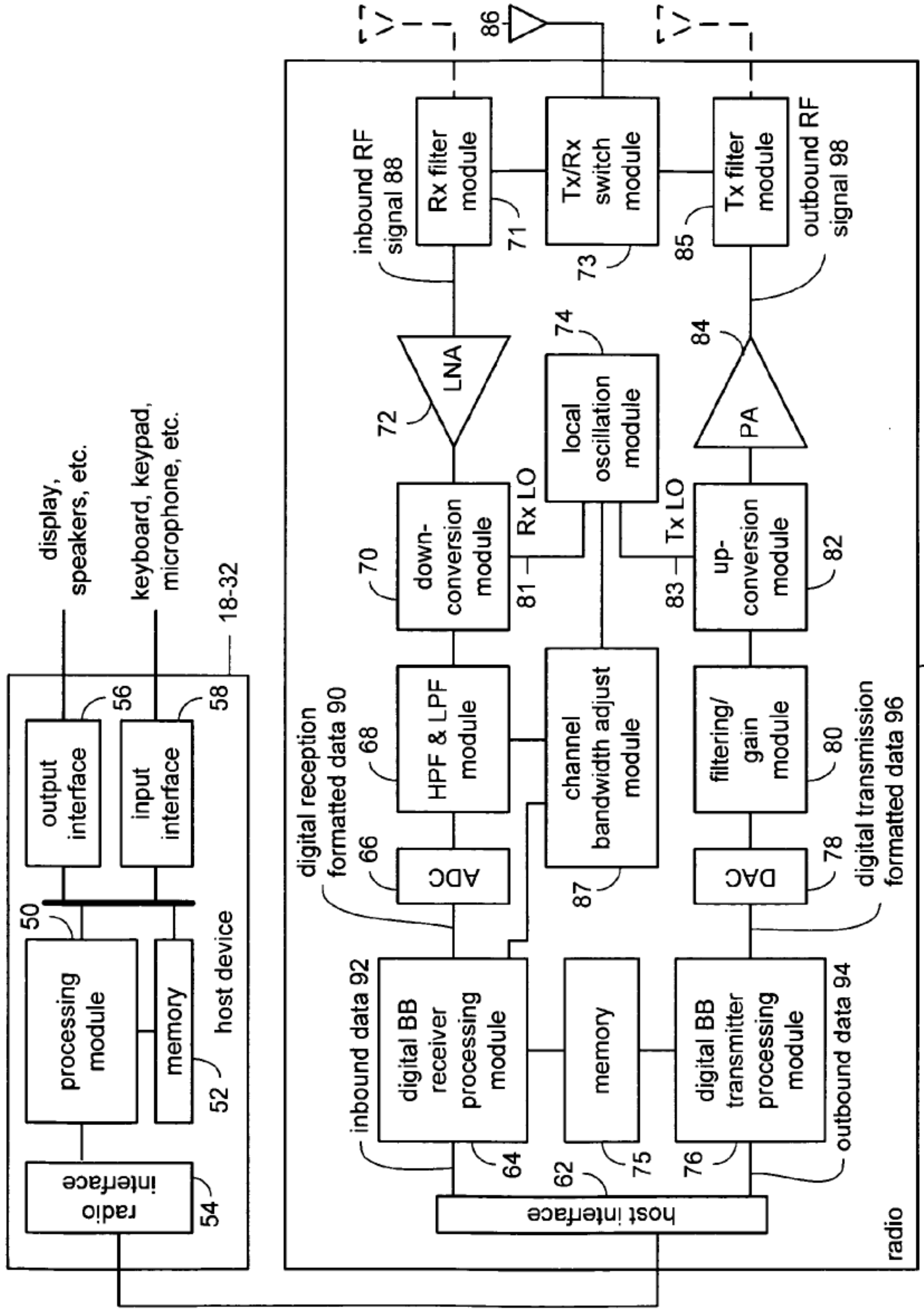
FIG. 1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keyboard, keypad, microphone, etc.
18-32
output interface
input interface
56
58
50
processing module
memory
52
host device
radio interface
54
host interface
62
radio
60
inbound data 92
digital BB receiver processing module
64
memory
75
digital BB transmitter processing module
76
outbound data 94
digital reception formatted data 90
ADC
66
HPF & LPF module
68
channel bandwidth adjust module
87
DAC
78
filtering/ gain module
80
digital transmission formatted data 96
down-conversion module
70
81
Rx LO
local oscillation module
74
Tx LO
83
up-conversion module
82
LNA
72
PA
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Rx filter module
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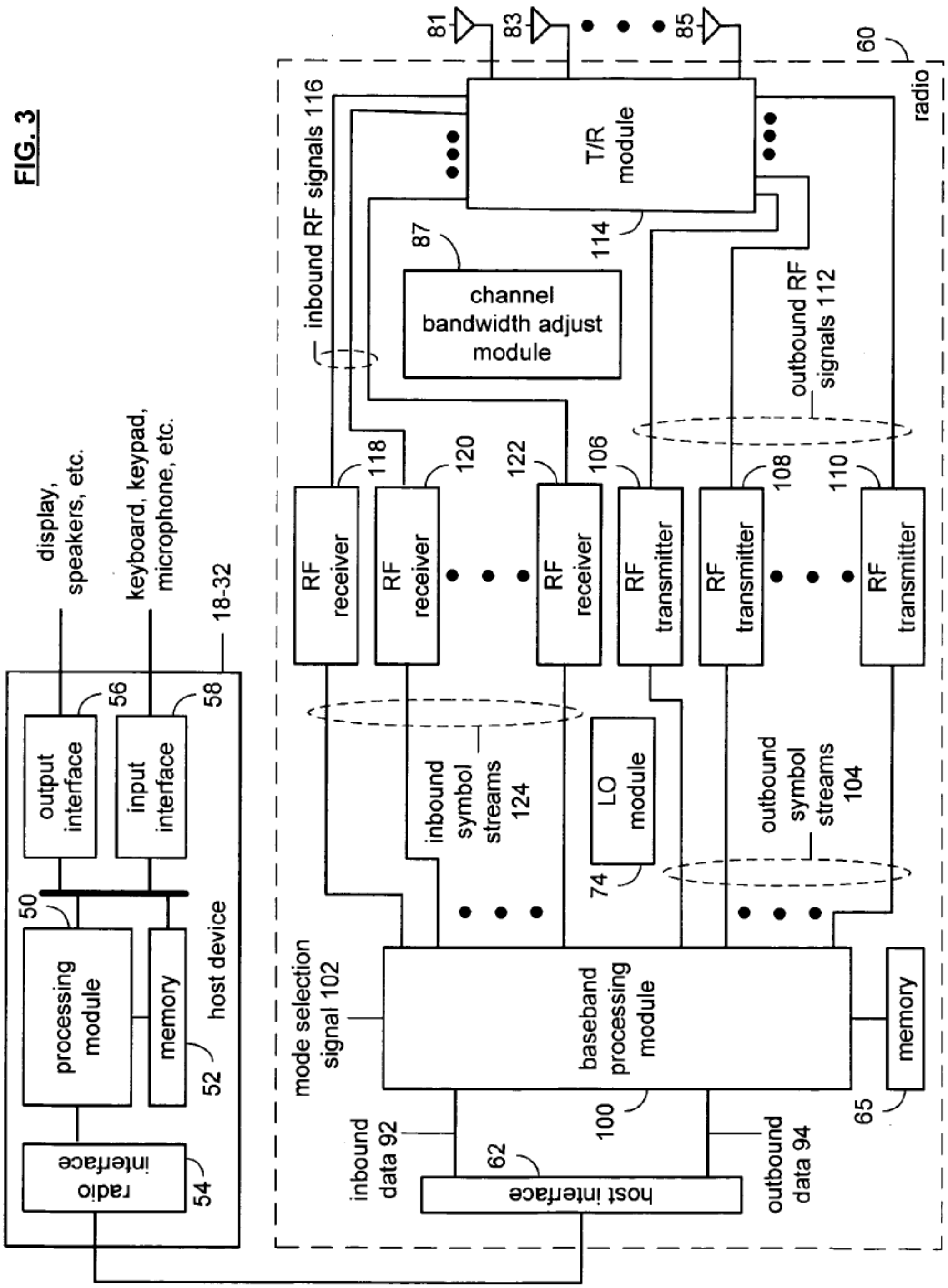
Tx/Rx switch module
73
Tx filter module
85
outbound RF signal 98
86

FIG. 2

FIG. 3


display, speakers, etc.
keyboard, keypad, microphone, etc.
18-32
output interface
56
input interface
58
50
processing module
memory
52
host device
radio interface
54
inbound RF signals 116
81
83
85
60
radio
T/R module
87
channel bandwidth adjust module
114
outbound RF signals 112
118
120
122
106
108
110
RF receiver
RF receiver
RF receiver
RF transmitter
RF transmitter
RF transmitter
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100
62
outbound data 94
host interface

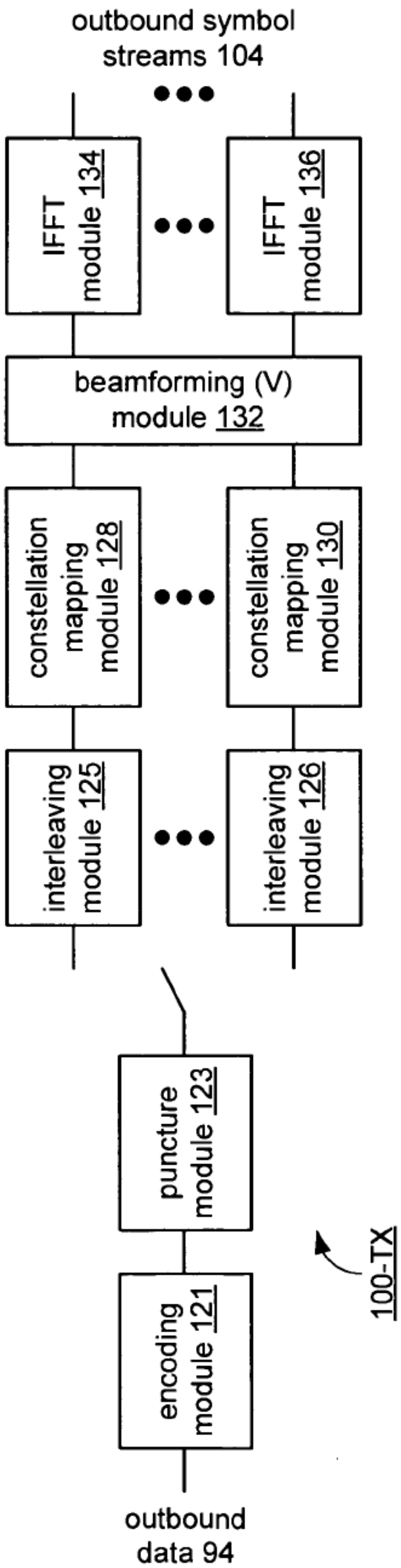
outbound symbol streams 104
IFFT module 134
IFFT module 136
beamforming (V) module 132
constellation mapping module 128
constellation mapping module 130
interleaving module 125
interleaving module 126
puncture module 123
encoding module 121
100-TX
outbound data 94

FIG. 4

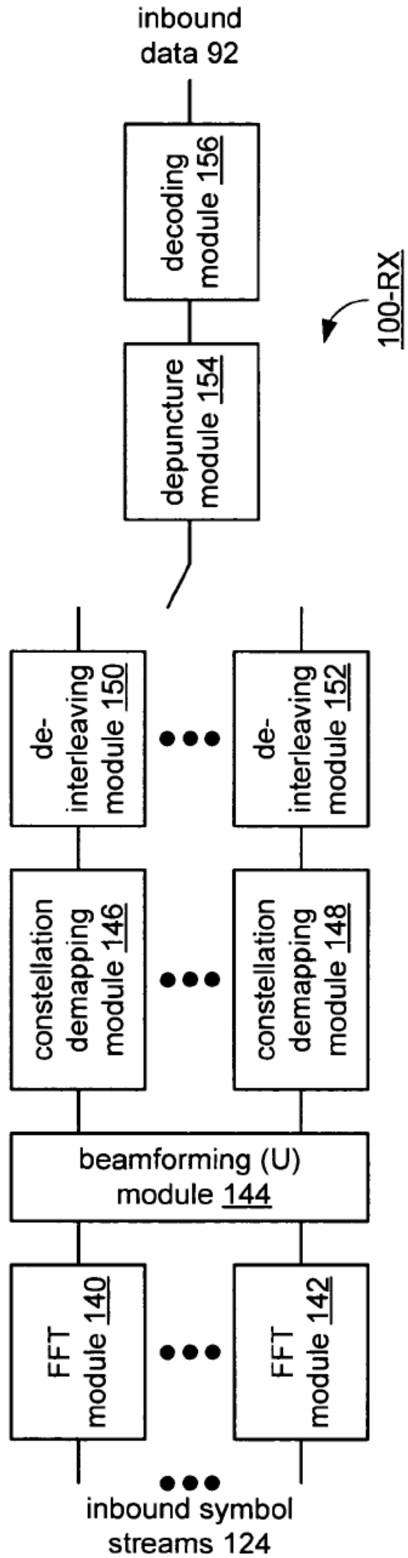
inbound data 92
decoding module 156
depuncture module 154
100-RX
de-interleaving module 150
de-interleaving module 152
constellation demapping module 146
constellation demapping module 148
beamforming (U) module 144
FFT module 140
FFT module 142
inbound symbol streams 124

FIG. 5

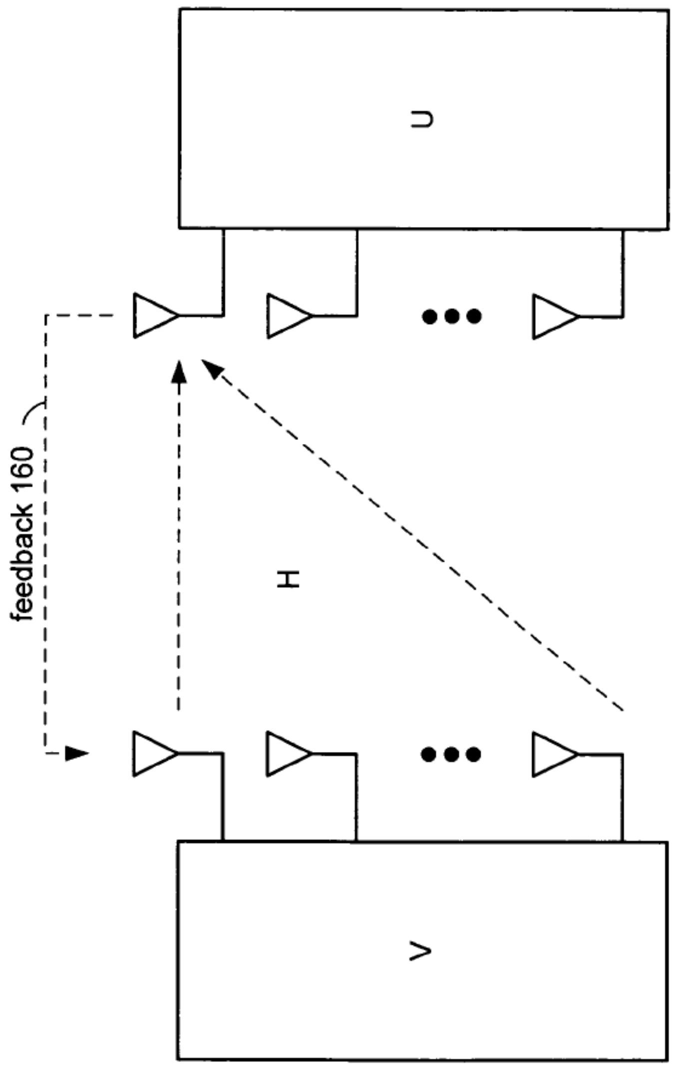

FIG. 6

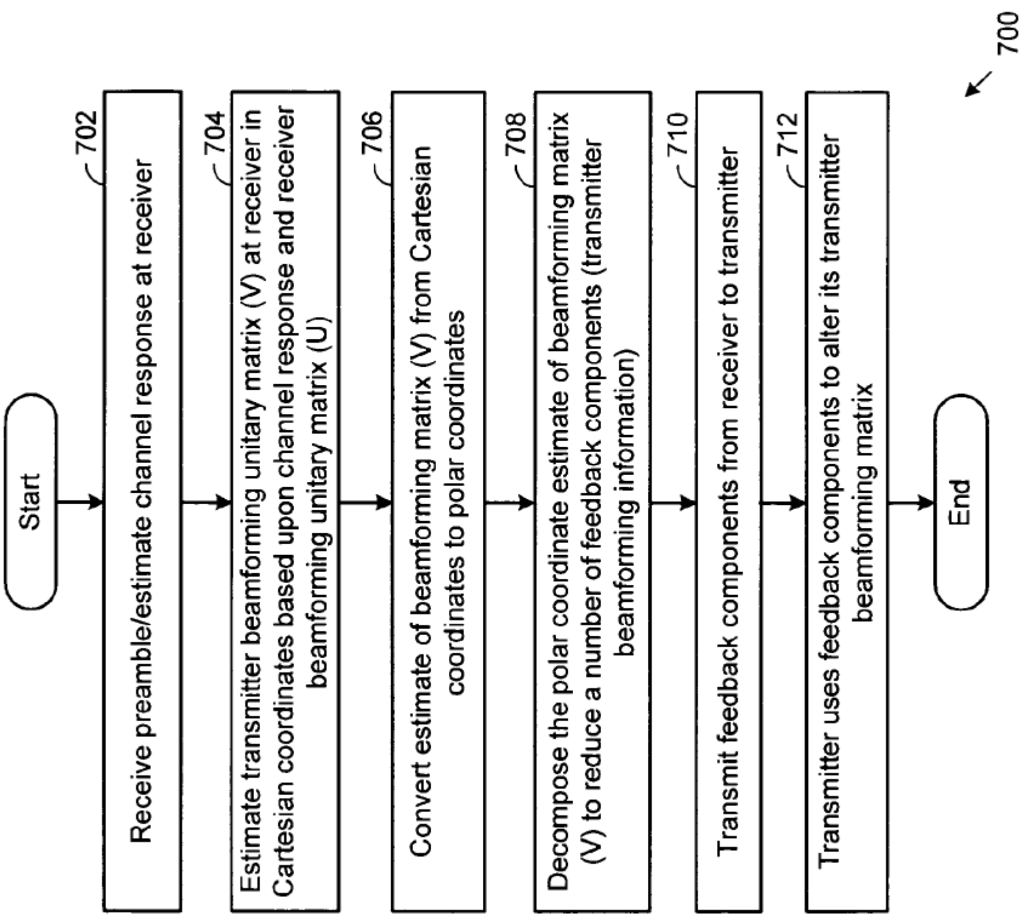
700
Start
Receive preamble/estimate channel response at receiver
702
Estimate transmitter beamforming unitary matrix (V) at receiver in Cartesian coordinates based upon channel response and receiver beamforming unitary matrix (U)
704
Convert estimate of beamforming matrix (V) from Cartesian coordinates to polar coordinates
706
Decompose the polar coordinate estimate of beamforming matrix (V) to reduce a number of feedback components (transmitter beamforming information)
708
Transmit feedback components from receiver to transmitter
710
Transmitter uses feedback components to alter its transmitter beamforming matrix
712
End

FIG. 7

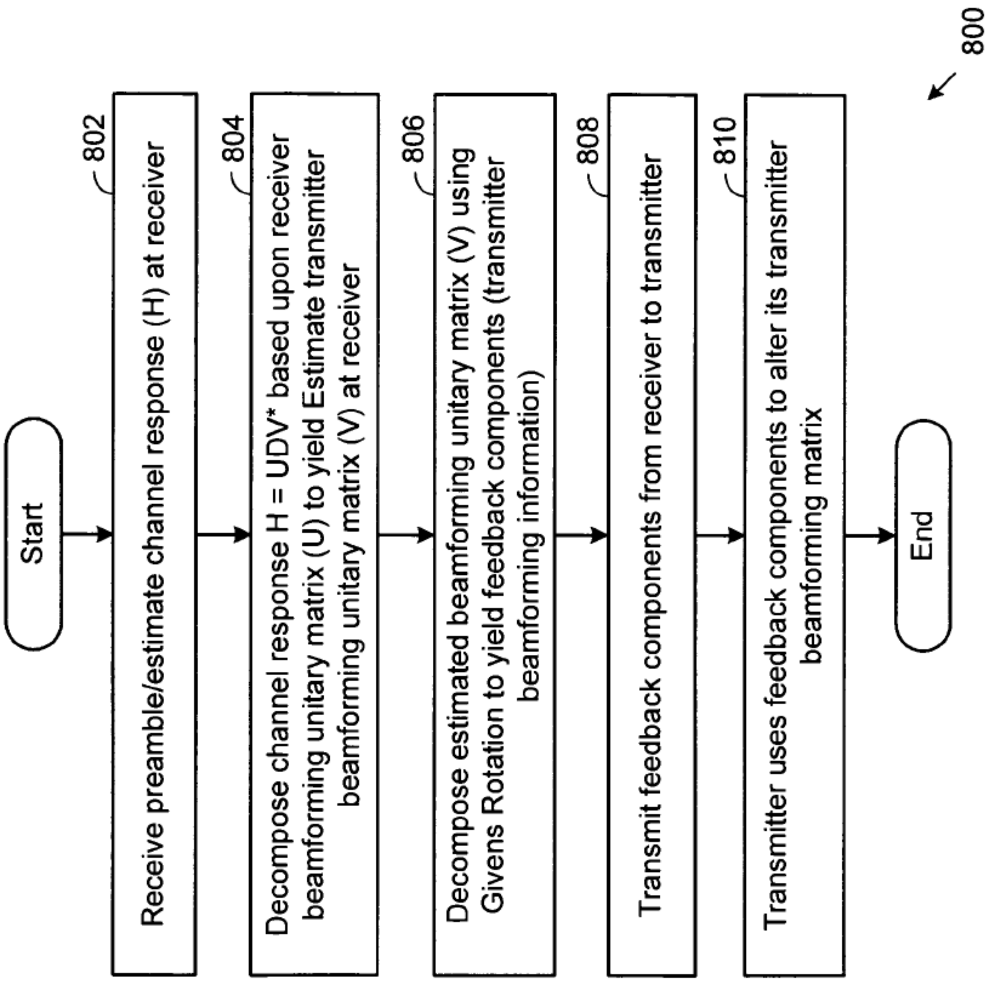
800
Start
802
Receive preamble/estimate channel response (H) at receiver
804
Decompose channel response H = UDV* based upon receiver beamforming unitary matrix (U) to yield Estimate transmitter beamforming unitary matrix (V) at receiver
806
Decompose estimated beamforming unitary matrix (V) using Givens Rotation to yield feedback components (transmitter beamforming information)
808
Transmit feedback components from receiver to transmitter
810
Transmitter uses feedback components to alter its transmitter beamforming matrix
End

FIG. 8

EFFICIENT FEEDBACK OF CHANNEL INFORMATION IN A CLOSED LOOP BEAMFORMING WIRELESS COMMUNICATION SYSTEM

CROSS REFERENCES TO RELATED APPLICATIONS

This application is a continuation-in-part of U.S. Utility application Ser. No. 11/168,793, filed Jun. 28, 2005 which claims priority to U.S. Provisional Patent Application Ser. No. 60/673,451, filed Apr. 21, 2005, and this application also claims priority to U.S. Provisional Patent Application Ser. No. 60/698,686, filed Jul. 13, 2005, all of which are incorporated herein by reference for all purposes.

BACKGROUND OF THE INVENTION

1. Technical Field of the Invention

This invention relates generally to wireless communication systems and more particularly to wireless communications using beamforming.

2. Description of Related Art

Communication systems are known to support wireless and wire lined communications between wireless and/or wire lined communication devices. Such communication systems range from national and/or international cellular telephone systems to the Internet to point-to-point in-home wireless networks. Each type of communication system is constructed, and hence operates, in accordance with one or more communication standards. For instance, wireless communication systems may operate in accordance with one or more standards including, but not limited to, IEEE 802.11, Bluetooth, advanced mobile phone services (AMPS), digital AMPS, global system for mobile communications (GSM), code division multiple access (CDMA), local multi-point distribution systems (LMDS), multi-channel-multi-point distribution systems (MMDS), and/or variations thereof.

Depending on the type of wireless communication system, a wireless communication device, such as a cellular telephone, two-way radio, personal digital assistant (PDA), personal computer (PC), laptop computer, home entertainment equipment, et cetera communicates directly or indirectly with other wireless communication devices. For direct communications (also known as point-to-point communications), the participating wireless communication devices tune their receivers and transmitters to the same channel or channels (e.g., one of the plurality of radio frequency (RF) carriers of the wireless communication system) and communicate over that channel(s). For indirect wireless communications, each wireless communication device communicates directly with an associated base station (e.g., for cellular services) and/or an associated access point (e.g., for an in-home or in-building wireless network) via an assigned channel. To complete a communication connection between the wireless communication devices, the associated base stations and/or associated access points communicate with each other directly, via a system controller, via the public switch telephone network, via the Internet, and/or via some other wide area network.

For each wireless communication device to participate in wireless communications, it includes a built-in radio transceiver (i.e., receiver and transmitter) or is coupled to an associated radio transceiver (e.g., a station for in-home and/or in-building wireless communication networks, RF modem, etc.). As is known, the receiver is coupled to the antenna and includes a low noise amplifier, one or more intermediate frequency stages, a filtering stage, and a data recovery stage.

The low noise amplifier receives inbound RF signals via the antenna and amplifies then. The one or more intermediate frequency stages mix the amplified RF signals with one or more local oscillations to convert the amplified RF signal into baseband signals or intermediate frequency (IF) signals. The filtering stage filters the baseband signals or the IF signals to attenuate unwanted out of band signals to produce filtered signals. The data recovery stage recovers raw data from the filtered signals in accordance with the particular wireless communication standard.

As is also known, the transmitter includes a data modulation stage, one or more intermediate frequency stages, and a power amplifier. The data modulation stage converts raw data into baseband signals in accordance with a particular wireless communication standard. The one or more intermediate frequency stages mix the baseband signals with one or more local oscillations to produce RF signals. The power amplifier amplifies the RF signals prior to transmission via an antenna.

In many systems, the transmitter will include one antenna for transmitting the RF signals, which are received by a single antenna, or multiple antennas, of a receiver. When the receiver includes two or more antennas, the receiver will select one of them to receive the incoming RF signals. In this instance, the wireless communication between the transmitter and receiver is a single-output-single-input (SISO) communication, even if the receiver includes multiple antennas that are used as diversity antennas (i.e., selecting one of them to receive the incoming RF signals). For SISO wireless communications, a transceiver includes one transmitter and one receiver. Currently, most wireless local area networks (WLAN) that are IEEE 802.11, 802.11a, 802,11b, or 802.11g employ SISO wireless communications.

Other types of wireless communications include single-input-multiple-output (SIMO), multiple-input-single-output (MISO), and multiple-input-multiple-output (MIMO). In a SIMO wireless communication, a single transmitter processes data into radio frequency signals that are transmitted to a receiver. The receiver includes two or more antennas and two or more receiver paths. Each of the antennas receives the RF signals and provides them to a corresponding receiver path (e.g., LNA, down conversion module, filters, and ADCs). Each of the receiver paths processes the received RF signals to produce digital signals, which are combined and then processed to recapture the transmitted data.

For a multiple-input-single-output (MISO) wireless communication, the transmitter includes two or more transmission paths (e.g., digital to analog converter, filters, up-conversion module, and a power amplifier) that each converts a corresponding portion of baseband signals into RF signals, which are transmitted via corresponding antennas to a receiver. The receiver includes a single receiver path that receives the multiple RF signals from the transmitter. In this instance, the receiver uses beam forming to combine the multiple RF signals into one signal for processing.

For a multiple-input-multiple-output (MIMO) wireless communication, the transmitter and receiver each include multiple paths. In such a communication, the transmitter parallel processes data using a spatial and time encoding function to produce two or more streams of data. The transmitter includes multiple transmission paths to convert each stream of data into multiple RF signals. The receiver receives the multiple RF signals via multiple receiver paths that recapture the streams of data utilizing a spatial and time decoding function. The recaptured streams of data are combined and subsequently processed to recover the original data.

To further improve wireless communications, transceivers may incorporate beamforming. In general, beamforming is a processing technique to create a focused antenna beam by shifting a signal in time or in phase to provide gain of the signal in a desired direction and to attenuate the signal in other directions. Prior art papers (1) Digital beamforming basics (antennas) by Steyskal, Hans, Journal of Electronic Defense, Jul. 1, 1996; (2) Utilizing Digital Down converters for Efficient Digital Beamforming, by Clint Schreiner, Red River Engineering, no publication date; and (3) Interpolation Based Transmit Beamforming for MIMO-OFMD with Partial Feedback, by Jihoon Choi and Robert W. Heath, University of Texas, Department of Electrical and Computer Engineering, Wireless Networking and Communications Group, Sep. 13, 2003 discuss beamforming concepts.

In order for a transmitter to properly implement beamforming (i.e., determine the beamforming matrix [V]), it needs to know properties of the channel over which the wireless communication is conveyed. Accordingly, the receiver must provide feedback information for the transmitter to determine the properties of the channel. One approach for sending feedback from the receiver to the transmitter is for the receiver to determine the channel response (H) and to provide it as the feedback information. An issue with this approach is the size of the feedback packet, which may be so large that, during the time it takes to send it to the transmitter, the response of the channel has changed.

To reduce the size of the feedback, the receiver may decompose the channel using singular value decomposition (SVD) and send information relating only to a calculated value of the transmitter's beamforming matrix (V) as the feedback information. In this approach, the receiver calculates (V) based on $H=UDV^*$, where H is the channel response, D is a diagonal matrix, and U is a receiver unitary matrix. While this approach reduces the size of the feedback information, its size is still an issue for a MIMO wireless communication. For instance, in a 2×2 MIMO wireless communication, the feedback needs four elements that are all complex Cartesian coordinate values [V11 V12; V21 V22]. In general, $V_{ik}=a_{ik}+j*b_{ik}$, where aik and bik are values between [−1, 1]. Thus, with 1 bit express per each element for each of the real and imaginary components, aik and bik can be either −½ or ½, which requires 4×2×1=8 bits per tone. With 4 bit expressions per each element of V(f) in an orthogonal frequency division multiplexing (OFDM) 2×2 MIMO wireless communication, the number of bits required is 1728 per tone (e.g., 4*2*54*4=1728, 4 elements per tone, 2 bits for real and imaginary components per tone, 54 data tones per frame, and 4 bits per element), which requires overhead for a packet exchange that is too large for practical applications.

Therefore, a need exists for a method and apparatus for reducing beamforming feedback information for wireless communications.

BRIEF SUMMARY OF THE INVENTION

The present invention is directed to apparatus and methods of operation that are further described in the following Brief Description of the Drawings, the Detailed Description of the Invention, and the claims. Other features and advantages of the present invention will become apparent from the following detailed description of the invention made with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

FIG. **1** is a schematic block diagram of a wireless communication system in accordance with the present invention;

FIG. **2** is a schematic block diagram illustrating an embodiment of a wireless communication device in accordance with the present invention;

FIG. **3** is a schematic block diagram illustrating another embodiment of another wireless communication device in accordance with the present invention;

FIG. **4** is a schematic block diagram of baseband transmit processing in accordance with the present invention;

FIG. **5** is a schematic block diagram of baseband receive processing in accordance with the present invention;

FIG. **6** is a schematic block diagram of a beamforming wireless communication in accordance with the present invention;

FIG. **7** is a flow chart illustrating another embodiment of the present invention for providing beamforming feedback information from a receiver to a transmitter; and

FIG. **8** is a flow chart illustrating another embodiment of the present invention for providing beamforming feedback information from a receiver to a transmitter

DETAILED DESCRIPTION OF THE INVENTION

FIG. **1** is a schematic block diagram illustrating a communication system **10** that includes a plurality of base stations and/or access points **12**, **16**, a plurality of wireless communication devices **18-32** and a network hardware component **34**. Note that the network hardware **34**, which may be a router, switch, bridge, modem, system controller, et cetera provides a wide area network connection **42** for the communication system **10**. Further note that the wireless communication devices **18-32** may be laptop host computers **18** and **26**, personal digital assistant hosts **20** and **30**, personal computer hosts **24** and **32** and/or cellular telephone hosts **22** and **28**. The details of the wireless communication devices will be described in greater detail with reference to FIG. **2**.

Wireless communication devices **22**, **23**, and **24** are located within an independent basic service set (IBSS) area and communicate directly (i.e., point to point). In this configuration, these devices **22**, **23**, and **24** may only communicate with each other. To communicate with other wireless communication devices within the system **10** or to communicate outside of the system **10**, the devices **22**, **23**, and/or **24** need to affiliate with one of the base stations or access points **12** or **16**.

The base stations or access points **12**, **16** are located within basic service set (BSS) areas **11** and **13**, respectively, and are operably coupled to the network hardware **34** via local area network connections **36**, **38**. Such a connection provides the base station or access point **12**, **16** with connectivity to other devices within the system **10** and provides connectivity to other networks via the WAN connection **42**. To communicate with the wireless communication devices within its BSS **11** or **13**, each of the base stations or access points **12-16** has an associated antenna or antenna array. For instance, base station or access point **12** wirelessly communicates with wireless communication devices **18** and **20** while base station or access point **16** wirelessly communicates with wireless communication devices **26-32**. Typically, the wireless communication devices register with a particular base station or access point **12**, **16** to receive services from the communication system **10**.

Typically, base stations are used for cellular telephone systems and like-type systems, while access points are used for in-home or in-building wireless networks (e.g., IEEE 802.11 and versions thereof, Bluetooth, and/or any other type of radio frequency based network protocol). Regardless of the particular type of communication system, each wireless communication device includes a built-in radio and/or is coupled to a radio.

FIG. **2** is a schematic block diagram illustrating an embodiment of a wireless communication device that includes the host device **18-32** and an associated radio **60**. For cellular telephone hosts, the radio **60** is a built-in component. For personal digital assistants hosts, laptop hosts, and/or personal computer hosts, the radio **60** may be built-in or an externally coupled component.

As illustrated, the host device **18-32** includes a processing module **50**, memory **52**, a radio interface **54**, an input interface **58**, and an output interface **56**. The processing module **50** and memory **52** execute the corresponding instructions that are typically done by the host device. For example, for a cellular telephone host device, the processing module **50** performs the corresponding communication functions in accordance with a particular cellular telephone standard.

The radio interface **54** allows data to be received from and sent to the radio **60**. For data received from the radio **60** (e.g., inbound data), the radio interface **54** provides the data to the processing module **50** for further processing and/or routing to the output interface **56**. The output interface **56** provides connectivity to an output display device such as a display, monitor, speakers, et cetera such that the received data may be displayed. The radio interface **54** also provides data from the processing module **50** to the radio **60**. The processing module **50** may receive the outbound data from an input device such as a keyboard, keypad, microphone, et cetera via the input interface **58** or generate the data itself. For data received via the input interface **58**, the processing module **50** may perform a corresponding host function on the data and/or route it to the radio **60** via the radio interface **54**.

Radio **60** includes a host interface **62**, digital receiver processing module **64**, an analog-to-digital converter **66**, a high pass and low pass filter module **68**, an IF mixing down conversion stage **70**, a receiver filter **71**, a low noise amplifier **72**, a transmitter/receiver switch **73**, a local oscillation module **74**, memory **75**, a digital transmitter processing module **76**, a digital-to-analog converter **78**, a filtering/gain module **80**, an IF mixing up conversion stage **82**, a power amplifier **84**, a transmitter filter module **85**, a channel bandwidth adjust module **87**, and an antenna **86**. The antenna **86** may be a single antenna that is shared by transmit and receive paths as regulated by the TxRx switch **73**, or may include separate antennas for the transmit path and receive path. The antenna implementation will depend on the particular standard to which the wireless communication device is compliant.

The digital receiver processing module **64** and the digital transmitter processing module **76**, in combination with operational instructions stored in memory **75**, execute digital receiver functions and digital transmitter functions, respectively. The digital receiver functions include, but are not limited to, digital intermediate frequency to baseband conversion, demodulation, constellation demapping, descrambling, and/or decoding. The digital transmitter functions include, but are not limited to, encoding, scrambling, constellation mapping, modulation, and/or digital baseband to IF conversion. The digital receiver and transmitter processing modules **64** and **76** may be implemented using a shared processing device, individual processing devices, or a plurality of processing devices. Such a processing device may be a microprocessor, micro-controller, digital signal processor, microcomputer, central processing unit, field programmable gate array, programmable logic device, state machine, logic circuitry, analog circuitry, digital circuitry, and/or any device that manipulates signals (analog and/or digital) based on operational instructions. The memory **75** may be a single memory device or a plurality of memory devices. Such a memory device may be a read-only memory, random access memory, volatile memory, non-volatile memory, static memory, dynamic memory, flash memory, and/or any device that stores digital information. Note that when the processing module **64** and/or **76** implements one or more of its functions via a state machine, analog circuitry, digital circuitry, and/or logic circuitry, the memory storing the corresponding operational instructions is embedded with the circuitry comprising the state machine, analog circuitry, digital circuitry, and/or logic circuitry.

In operation, the radio **60** receives outbound data **94** from the host device via the host interface **62**. The host interface **62** routes the outbound data **94** to the digital transmitter processing module **76**, which processes the outbound data **94** in accordance with a particular wireless communication standard (e.g., IEEE 802.11, Bluetooth, et cetera) to produce digital transmission formatted data **96**. The digital transmission formatted data **96** will be digital base-band signals (e.g., have a zero IF) or a digital low IF signals, where the low IF typically will be in the frequency range of one hundred kilohertz to a few megahertz.

The digital-to-analog converter **78** converts the digital transmission formatted data **96** from the digital domain to the analog domain. The filtering/gain module **80** filters and/or adjusts the gain of the analog signals prior to providing it to the IF mixing stage **82**. The IF mixing stage **82** converts the analog baseband or low IF signals into RF signals based on a transmitter local oscillation **83** provided by local oscillation module **74**. The power amplifier **84** amplifies the RF signals to produce outbound RF signals **98**, which are filtered by the transmitter filter module **85**. The antenna **86** transmits the outbound RF signals **98** to a targeted device such as a base station, an access point and/or another wireless communication device.

The radio **60** also receives inbound RF signals **88** via the antenna **86**, which were transmitted by a base station, an access point, or another wireless communication device. The antenna **86** provides the inbound RF signals **88** to the receiver filter module **71** via the TxRx switch **73**, where the Rx filter **71** bandpass filters the inbound RF signals **88**. The Rx filter **71** provides the filtered RF signals to low noise amplifier **72**, which amplifies the signals **88** to produce an amplified inbound RF signals. The low noise amplifier **72** provides the amplified inbound RF signals to the IF mixing module **70**, which directly converts the amplified inbound RF signals into an inbound low IF signals or baseband signals based on a receiver local oscillation **81** provided by local oscillation module **74**. The down conversion module **70** provides the inbound low IF signals or baseband signals to the filtering/gain module **68**. The high pass and low pass filter module **68** filters, based on settings provided by the channel bandwidth adjust module **87**, the inbound low IF signals or the digital reception formatted data to produce filtered inbound signals.

The analog-to-digital converter **66** converts the filtered inbound signals from the analog domain to the digital domain to produce digital reception formatted data **90**, where the digital reception formatted data **90** will be digital base-band signals or digital low IF signals, where the low IF typically will be in the frequency range of one hundred kilohertz to a few megahertz. The digital receiver processing module **64**, based on settings provided by the channel bandwidth adjust module **87**, decodes, descrambles, demaps, and/or demodulates the digital reception formatted data **90** to recapture inbound data **92** in accordance with the particular wireless communication standard being implemented by radio **60**. The host interface **62** provides the recaptured inbound data **92** to the host device **18-32** via the radio interface **54**.

As one of average skill in the art will appreciate, the wireless communication device of FIG. **2** may be implemented using one or more integrated circuits. For example, the host device may be implemented on one integrated circuit, the digital receiver processing module **64**, the digital transmitter processing module **76** and memory **75** may be implemented on a second integrated circuit, and the remaining components of the radio **60**, less the antenna **86**, may be implemented on a third integrated circuit. As an alternate example, the radio **60** may be implemented on a single integrated circuit. As yet another example, the processing module **50** of the host device and the digital receiver and transmitter processing modules **64** and **76** may be a common processing device implemented on a single integrated circuit. Further, the memory **52** and memory **75** may be implemented on a single integrated circuit and/or on the same integrated circuit as the common processing modules of processing module **50** and the digital receiver and transmitter processing module **64** and **76**.

FIG. **3** is a schematic block diagram illustrating another embodiment of a wireless communication device that includes the host device **18-32** and an associated radio **60**. For cellular telephone hosts, the radio **60** is a built-in component. For personal digital assistants hosts, laptop hosts, and/or personal computer hosts, the radio **60** may be built-in or an externally coupled component.

As illustrated, the host device **18-32** includes a processing module **50**, memory **52**, radio interface **54**, input interface **58** and output interface **56**. The processing module **50** and memory **52** execute the corresponding instructions that are typically done by the host device. For example, for a cellular telephone host device, the processing module **50** performs the corresponding communication functions in accordance with a particular cellular telephone standard.

The radio interface **54** allows data to be received from and sent to the radio **60**. For data received from the radio **60** (e.g., inbound data), the radio interface **54** provides the data to the processing module **50** for further processing and/or routing to the output interface **56**. The output interface **56** provides connectivity to an output display device such as a display, monitor, speakers, et cetera such that the received data may be displayed. The radio interface **54** also provides data from the processing module **50** to the radio **60**. The processing module **50** may receive the outbound data from an input device such as a keyboard, keypad, microphone, et cetera via the input interface **58** or generate the data itself. For data received via the input interface **58**, the processing module **50** may perform a corresponding host function on the data and/or route it to the radio **60** via the radio interface **54**.

Radio **60** includes a host interface **62**, a baseband processing module **100**, memory **65**, a plurality of radio frequency (RF) transmitters **106-110**, a transmit/receive (T/R) module **114**, a plurality of antennas **81-85**, a plurality of RF receivers **118-120**, a channel bandwidth adjust module **87**, and a local oscillation module **74**. The baseband processing module **100**, in combination with operational instructions stored in memory **65**, executes digital receiver functions and digital transmitter functions, respectively. The digital receiver functions include, but are not limited to, digital intermediate frequency to baseband conversion, demodulation, constellation demapping, decoding, de-interleaving, fast Fourier transform, cyclic prefix removal, space and time decoding, and/or descrambling. The digital transmitter functions include, but are not limited to, encoding, scrambling, interleaving, constellation mapping, modulation, inverse fast Fourier transform, cyclic prefix addition, space and time encoding, and digital baseband to IF conversion. The baseband processing modules **100** may be implemented using one or more processing devices. Such a processing device may be a microprocessor, micro-controller, digital signal processor, microcomputer, central processing unit, field programmable gate array, programmable logic device, state machine, logic circuitry, analog circuitry, digital circuitry, and/or any device that manipulates signals (analog and/or digital) based on operational instructions. The memory **65** may be a single memory device or a plurality of memory devices. Such a memory device may be a read-only memory, random access memory, volatile memory, non-volatile memory, static memory, dynamic memory, flash memory, and/or any device that stores digital information. Note that when the processing module **100** implements one or more of its functions via a state machine, analog circuitry, digital circuitry, and/or logic circuitry, the memory storing the corresponding operational instructions is embedded with the circuitry comprising the state machine, analog circuitry, digital circuitry, and/or logic circuitry.

In operation, the radio **60** receives outbound data **94** from the host device via the host interface **62**. The baseband processing module **64** receives the outbound data **94** and, based on a mode selection signal **102**, produces one or more outbound symbol streams **104**. The mode selection signal **102** will indicate a particular mode of operation that is compliant with one or more specific modes of the various IEEE 802.11 standards. For example, the mode selection signal **102** may indicate a frequency band of 2.4 GHz, a channel bandwidth of 20 or 22 MHz and a maximum bit rate of 54 megabits-per-second. In this general category, the mode selection signal will further indicate a particular rate ranging from 1 megabit-per-second to 54 megabits-per-second. In addition, the mode selection signal will indicate a particular type of modulation, which includes, but is not limited to, Barker Code Modulation, BPSK, QPSK, CCK, 16 QAM and/or 64 QAM. The mode select signal **102** may also include a code rate, a number of coded bits per subcarrier (NBPSC), coded bits per OFDM symbol (NCBPS), and/or data bits per OFDM symbol (NDBPS). The mode selection signal **102** may also indicate a particular channelization for the corresponding mode that provides a channel number and corresponding center frequency. The mode select signal **102** may further indicate a power spectral density mask value and a number of antennas to be initially used for a MIMO communication.

The baseband processing module **100**, based on the mode selection signal **102** produces one or more outbound symbol streams **104** from the outbound data **94**. For example, if the mode selection signal **102** indicates that a single transmit antenna is being utilized for the particular mode that has been selected, the baseband processing module **100** will produce a single outbound symbol stream **104**. Alternatively, if the mode select signal **102** indicates 2, 3 or 4 antennas, the baseband processing module **100** will produce 2, 3 or 4 outbound symbol streams **104** from the outbound data **94**.

Depending on the number of outbound streams **104** produced by the baseband module **10**, a corresponding number of the RF transmitters **106-110** will be enabled to up convert the outbound symbol streams **104** into outbound RF signals **112**. In general, each of the RF transmitters **106-110** includes a digital filter and upsampling module, a digital to analog conversion module, an analog filter module, a frequency up conversion module, a power amplifier, and a radio frequency bandpass filter. The RF transmitters **106-110** provide the outbound RF signals **112** to the transmit/receive module **114**, which provides each outbound RF signal to a corresponding antenna **81-85**.

When the radio **60** is in the receive mode, the transmit/receive module **114** receives one or more inbound RF signals **116** via the antennas **81-85** and provides them to one or more RF receivers **118-122**. The RF receiver **118-122**, based on settings provided by the channel bandwidth adjust module **87**, down converts the inbound RF signals **116** into a corresponding number of inbound symbol streams **124**. The number of inbound symbol streams **124** will correspond to the particular mode in which the data was received. The baseband processing module **100** converts the inbound symbol streams **124** into inbound data **92**, which is provided to the host device **18-32** via the host interface **62**.

As one of average skill in the art will appreciate, the wireless communication device of FIG. **3** may be implemented using one or more integrated circuits. For example, the host device may be implemented on one integrated circuit, the baseband processing module **100** and memory **65** may be implemented on a second integrated circuit, and the remaining components of the radio **60**, less the antennas **81-85**, may be implemented on a third integrated circuit. As an alternate example, the radio **60** may be implemented on a single integrated circuit. As yet another example, the processing module **50** of the host device and the baseband processing module **100** may be a common processing device implemented on a single integrated circuit. Further, the memory **52** and memory **65** may be implemented on a single integrated circuit and/or on the same integrated circuit as the common processing modules of processing module **50** and the baseband processing module **100**.

FIG. **4** is a schematic block diagram of baseband transmit processing 100-TX within the baseband processing module **100**, which includes an encoding module **121**, a puncture module **123**, a switch, a plurality of interleaving modules **125**, **126**, a plurality of constellation encoding modules **128**, **130**, a beamforming module (V) **132**, and a plurality of inverse fast Fourier transform (IFFT) modules **134**, **136** for converting the outbound data **94** into the outbound symbol stream(s) **104**. As one of ordinary skill in the art will appreciate, the baseband transmit processing may include two or more of each of the interleaving modules **125**, **126**, the constellation mapping modules **128**, **130**, and the IFFT modules **134**, **136**. In addition, one of ordinary skill in art will further appreciate that the encoding module **121**, puncture module **123**, the interleaving modules **124**, **126**, the constellation mapping modules **128**, **130**, and the IFFT modules **134**, **136** may function in accordance with one or more wireless communication standards including, but not limited to, IEEE 802.11a, b, g, n.

In one embodiment, the encoding module **121** is operably coupled to convert outbound data **94** into encoded data in accordance with one or more wireless communication standards. The puncture module **123** punctures the encoded data to produce punctured encoded data. The plurality of interleaving modules **125**, **126** is operably coupled to interleave the punctured encoded data into a plurality of interleaved streams of data. The plurality of constellation mapping modules **128**, **130** is operably coupled to map the plurality of interleaved streams of data into a plurality of streams of data symbols. The beamforming module **132** is operably coupled to beamform, using a unitary matrix having polar coordinates, the plurality of streams of data symbols into a plurality of streams of beamformed symbols. The plurality of IFFT modules **134**, **136** is operably coupled to convert the plurality of streams of beamformed symbols into a plurality of outbound symbol streams.

The beamforming module **132** is operably coupled to multiply a beamforming unitary matrix (V) with baseband signals provided by the plurality of constellation mapping modules **128**, **130**. The beamforming module **132** determines the beamforming unitary matrix V from feedback information from the receiver, wherein the feedback information includes a calculated expression of the beamforming matrix V having polar coordinates. The beamforming module **132** generates the beamforming unitary matrix V to satisfy the conditions of "V*V=VV*="I", where "I" is an identity matrix of [1 0; 0 1] for 2×2 MIMO wireless communication, is [1 0 0; 0 1 0; 0 0 1] for 3×3 MIMO wireless communication, or is [1 0 0 0; 0 1 0 0; 0 0 1 0; 0 0 0 1] for 4×4 MIMO wireless communication. In this equation, V*V means "conjugate (V) times V" and VV* means "V times conjugate (V)". Note that V may be a 2×2 unitary matrix for a 2×2 MIMO wireless communication, a 3×3 unitary matrix for a 3×3 MIMO wireless communication, and a 4×4 unitary matrix for a 4×4 MIMO wireless communication. Further note that for each column of V, a first row of polar coordinates including real values as references and a second row of polar coordinates including phase shift values.

In one embodiment, the constellation mapping modules **128**, **130** function in accordance with one of the IEEE 802.11x standards to provide an OFDM (Orthogonal Frequency Domain Multiplexing) frequency domain baseband signals that includes a plurality of tones, or subcarriers, for carrying data. Each of the data carrying tones represents a symbol mapped to a point on a modulation dependent constellation map. For instance, a 16 QAM (Quadrature Amplitude Modulation) includes 16 constellation points, each corresponding to a different symbol. For an OFDM signal, the beamforming module **132** may regenerate the beamforming unitary matrix V for each tone from each constellation mapping module **128**, **130**, use the same beamforming unitary matrix for each tone from each constellation mapping module **128**, **130**, or a combination thereof.

The beamforming unitary matrix varies depending on the number of transmit paths (i.e., transmit antennas−M) and the number of receive paths (i.e., receiver antennas−N) for an M×N MIMO communication. For instance, for a 2×2 MIMO communication, the beamforming unitary matrix may be:

$$V=(V)ij=\begin{bmatrix}\cos\psi_1 & \cos\psi_2\\ \sin\psi_1 e^{j\phi_1} & \sin\psi_2 e^{j\phi_2}\end{bmatrix}$$

In order to satisfy V*V=I, it needs to satisfy followings.

$$\cos\psi_1\cos\psi_2+\sin\psi_1\sin\psi_2 e^{j(\Phi_1-\Phi_2)}=0$$

$$\cos\psi_1\cos\psi_2+\sin\psi_1\sin\psi_2 e^{j(\Phi_2-100_2)}=0$$

Where i, j=1, 2; ψ_1, Φ_1, ψ_2, and Φ_2 represent angles of the unit circle, wherein absolute value of $\psi_1-\psi_2=\pi/2$ and $\Phi_1=\Phi_2$ or $\Phi_1=\Phi_2+\pi$ and $\psi_1+\psi_2=\pi/2$.

Therefore, with Φ_1 and ψ_1, the beamforming module **132** may regenerate V per each tone. For example, With 4-bits expression for angle Φ_1 and 3-bits for angle ψ_1, and 1-bit for the index for #1 or #2 in 54 tones, (i.e., 8-bits per tone) total feedback information may be 8×54/8=54 bytes. (ψ in [0, π]Φ in [−$\pi\pi$]).

For a 3×3 MIMO communication, the beamforming unitary matrix may be:

$$V = (V)ij = \begin{bmatrix} \cos\psi_1 & \cos\psi_2 & \cos\psi_3 \\ \sin\psi_1\cos\theta_1 e^{j\phi_{21}} & \sin\psi_2\cos\theta_2 e^{j\phi_{22}} & \sin\psi_3\cos\theta_3 e^{j\phi_{23}} \\ \sin\psi_1\sin\theta_1 e^{j\phi_{31}} & \sin\psi_2\sin\theta_2 e^{j\phi_{32}} & \sin\psi_3\sin\theta_3 e^{j\phi_{33}} \end{bmatrix}$$

where i, j=1, 2, 3; ψ_1, ψ_2, ψ_3, θ_1, θ_2, θ_3, Φ_{21}, Φ_{22}, Φ_{23}, Φ_{32}, Φ_{33} represent angles of the unit circle, wherein Diagonal (V*V)=1s, and wherein:

$$\psi_i = \cos^{-1} V_{1i},\ \theta_i = \cos^{-1}\left|\frac{V_{2i}}{\sin\psi_i}\right|$$

$$\phi_{2i} = \angle(V_{2i}),\ \phi_{3i} = \angle(V_{3i})$$

In this example, with 12 angles, the beamforming module **132** may regenerate V as a 3×3 matrix per tone. With 4-bits for expression for the angles, a 54 tone signal may have feedback information of 324 bytes (e.g., 4×12×54/8).

For a 4×4 MIMO communication, the beamforming unitary matrix may be:

$$V = (V)ij = \begin{bmatrix} \cos\psi_1\cos\varphi_1 & \cos\psi_2\cos\varphi_2 & \cos\psi_3\cos\varphi_3 & \cos\psi_4\cos\varphi_4 \\ \cos\psi_1\sin\varphi_1 e^{j\phi_{11}} & \cos\psi_2\sin\varphi_2 e^{j\phi_{12}} & \cos\psi_3\sin\varphi_3 e^{j\phi_{13}} & \cos\psi_4\sin\varphi_4 e^{j\phi_{14}} \\ \sin\psi_1\cos\theta_1 e^{j\phi_{21}} & \sin\psi_2\cos\theta_2 e^{j\phi_{22}} & \sin\psi_3\cos\theta_3 e^{j\phi_{23}} & \sin\psi_4\cos\theta_4 e^{j\phi_{24}} \\ \sin\psi_1\sin\theta_1 e^{j\phi_{31}} & \sin\psi_2\sin\theta_2 e^{j\phi_{32}} & \sin\psi_3\sin\theta_3 e^{j\phi_{33}} & \sin\psi_4\sin\theta_4 e^{j\phi_{34}} \end{bmatrix} =$$

[$\cos(\psi_1)\cos(\Phi_2)$; $\sin(\psi_1)*e^{j\Phi 1}$ $\sin(\psi_2)*e^{j\Phi 2}$], where i,j=1, 2, 3, 4; wherein ψ_1, ψ_2, ψ_3, ψ_4, θ_1, θ_2, θ_3, θ_4, ϕ_1, ϕ_2, ϕ_3, ϕ_4, Φ_{21}, Φ_{22}, Φ_{23}, Φ_{24}, Φ_{31}, Φ_{32}, Φ_{33}, Φ_{33}, Φ_{41}, Φ_{42}, Φ_{43}, Φ_{43} represent angles of the unit circle, wherein Diagonal (V*V)=1s, and wherein:

$$\psi_i = \cos^{-1}\left(\sqrt{|V_{1i}|^2 + |V_{2i}|^2}\right),$$

$$\varphi_i = \cos^{-1}\left(\frac{V_{1i}}{\cos\psi_i}\right),$$

$$\theta_i = \cos^{-1}\left|\frac{V_{3i}}{\sin\psi_i}\right|$$

$$\phi_{1i} = \angle(V_{2i}),$$

$$\phi_{2i} = \angle(V_{3i}),$$

$$\phi_{3i} = \angle(V_{4i})$$

In this example, with 24 angles, the beamforming module **132** may regenerate V as a 4×4 matrix per tone. With 4-bits for expression for the angles, a 54 tone signal may have feedback information of 648 bytes (e.g., 4×24×54/8).

The baseband transmit processing 100-TX receives the polar coordinates Φ andψ V from the receiver as feedback information as will described in greater detail with reference to FIG. **6**.

FIG. **5** is a schematic block diagram of baseband receive processing 100-RX that includes a plurality of fast Fourier transform (FFT) modules **140**, **142**, a beamforming (U) module **144**, a plurality of constellation demapping modules **146**, **148**, a plurality of deinterleaving modules **150**, **152**, a switch, a depuncture module **154**, and a decoding module **156** for converting a plurality of inbound symbol streams **124** into inbound data **92**. As one of ordinary skill in the art will appreciate, the baseband receive processing 100-RX may include two or more of each of the deinterleaving modules **150**, **152**, the constellation demapping modules **146**, **148**, and the FFT modules **140**, **142**. In addition, one of ordinary skill in art will further appreciate that the decoding module **156**, depuncture module **154**, the deinterleaving modules **150**, **152**, the constellation decoding modules **146**, **148**, and the FFT modules **140**, **142** may be function in accordance with one or more wireless communication standards including, but not limited to, IEEE 802.11a, b, g, n.

In one embodiment, a plurality of FFT modules **140**, **142** is operably coupled to convert a plurality of inbound symbol streams **124** into a plurality of streams of beamformed symbols. The inverse beamforming module **144** is operably coupled to inverse beamform, using a unitary matrix having polar coordinates, the plurality of streams of beamformed symbols into a plurality of streams of data symbols. The plurality of constellation demapping modules is operably coupled to demap the plurality of streams of data symbols into a plurality of interleaved streams of data. The plurality of deinterleaving modules is operably coupled to deinterleave the plurality of interleaved streams of data into encoded data. The decoding module is operably coupled to convert the encoded data into inbound data **92**.

The beamforming module **144** is operably coupled to multiply a beamforming unitary matrix (U) with baseband signals provided by the plurality of FFT modules **140**, **142**. The FFT modules **140**, **142** function in accordance with one of the IEEE 802.11x standards to provide an OFDM (Orthogonal Frequency Domain Multiplexing) frequency domain baseband signals that includes a plurality of tones, or subcarriers, for carrying data. Each of the data carrying tones represents a symbol mapped to a point on a modulation dependent constellation map. The baseband receive processing 100-RX is further functional to produce feedback information for the transmitter as further described with reference to FIG. **6**.

FIG. **6** is a schematic block diagram of a beamforming wireless communication where H=UDV* (H—represents the channel, U is the receiver beamforming unitary matrix, and V* is the conjugate of the transmitter beamforming unitary matrix. With H=UDV*, y (the received signal)=Hx+N, where x represents the transmitted signals and N represents noise. If z=Vx, then U*y=U*UDV*Vz+U*n=Dz+N.

From this expression, the baseband receive processing 100-RX may readily determine the feedback of V, where V includes polar coordinates. For instance, the receiver may decompose the channel using singular value decomposition (SVD) and send information relating only to a calculated value of the transmitter's beamforming matrix (V) as the feedback information. In this approach, the receiver calculates (V) based on H=UDV*, where H is the channel response, D is a diagonal matrix, and U is a receiver unitary matrix. This approach reduces the size of the feedback information with respect to SVD using Cartesian coordinates. For example, in a 2×2 MIMO wireless communication, the feedback needs four elements that are all complex values [V11 V12; V21 V22] with two angles (ψ and Φ). In general, Vik=aik+j*bik, where aik and bik are values between [−1, 1]. To cover [−1, 1], ψ is in [0, π] and Φ is in [0, 2π]. With π/2 resolutions for angles, ψ needs to be π/4 or 3π/4, i.e., cos(ψ)=0.707 or −0.707, which requires 1 bit, where Φ needs to be either π/4, 3π/4, 5π/4, 7π/4, i.e., exp(j Φ)=0.707(1+j), 0.707 (1−j), 0.707(−1+j) or 0.707(−1−j), which requires 2 bits. With π/4 resolutions for angles, ψ needs to be π/8, 3π/8, 5π/8, or 7π/8, which requires 2 bits, where Φ needs to be either π/8, 3π/8, 5π8, 7π/8, 9π8, 11π/8, 13π/8 or 15π/8, which requires 4 bits. So, for an example of 2×2 system to use 4 bits per tone, it may have 1 bit for ψ, 2 bits for 4) and 1 index bit to determine the relationship between ψ and Φ, such as either ψ1=ψ2+π and Φ1+Φ2=π/2, or ψ1=ψ2 and Φ1−Φ2=π/2.

For the same resolution in Cartesian expression of 4 bits per each element for each of the real and imaginary components, aik and bik, can be within [−½, ½], it requires 4*2*4=32 bits per tone. For OFDM MIMO wireless communications, the number of bits required is 1728 bits for the Cartesian expression. While an angle expression in accordance with the present invention requires 8 bits per tone, which for the same OFDM MIMO wireless communications would require 432 bits. This represents a significant reduction in the overhead needed for packet exchange.

FIG. **7** is a flow chart illustrating another embodiment of the present invention for providing beamforming feedback information from a receiver to a transmitter. The method **700** in particular addresses the feed back of observed transmitter beamforming information from a receiving wireless communication device to a transmitting wireless communication device. The method **700** of FIG. **7** relates to MIMO wireless communication systems, among others. Most of the operations **700** of FIG. **7** are typically performed by a baseband processing module, e.g., **100** of FIG. **3** of a receiving wireless device.

The method **700** commences with the receiving wireless communication device receiving a preamble sequence from the transmitting wireless device and estimating a channel response from the preamble sequence (step **702**). Estimating the channel response includes comparing received training symbols of the preamble to corresponding expected training symbols using any of a number of techniques that are known in the art. The receiving wireless device then determines an estimated transmitter beamforming unitary matrix (V) based upon the channel response and a known receiver beamforming unitary matrix (U) (step **704**). The channel response (H), estimated transmitter beamforming unitary matrix (V), and the known receiver beamforming unitary matrix (U) are related by the equation H=UDV*, where, D is a diagonal matrix. Singular Value Decomposition (SVD) operations may be employed to produce the estimated transmitter beamforming unitary matrix (V) according to this equation.

According to the embodiment of FIG. **7**, the receiving wireless device produces the estimated transmitter beamforming unitary matrix (V) in Cartesian coordinates and then converts the estimated transmitter beamforming unitary matrix (V) to polar coordinates (step **706**). With the estimated transmitter beamforming unitary matrix (V) determined, the receiving wireless device then decomposes the estimated transmitter beamforming unitary matrix (V) to produce the transmitter beamforming information (step **708**).

According to one embodiment of this operation, the decomposition operations of step **708** employ a Givens Rotation operation. The Givens Rotation relies upon the observation that, with the condition of V*V=VV*=I, some of angles of the Givens Rotation are redundant. With a decomposed matrix form for the estimated transmitter beamforming matrix (V), the set of angles fed back to the transmitting wireless device are reduced.

Operation continues with the receiving wireless device wirelessly sending the transmitter beamforming information to the transmitting wireless device (step **710**). This operation occurs with the receiving wireless device shifting to a transmit mode and sending the information back to the transmitting wireless device. The transmitting wireless device then uses the feedback components to generate a new beamforming matrix (V), which it uses for subsequent transmissions (step **712**).

FIG. **8** is a flow chart illustrating another embodiment of the present invention for providing beamforming feedback information from a receiver to a transmitter. The operations **800** of FIG. **8** are similar to the operations **700** of FIG. **7** and would typically be performed by a baseband processing module, e.g., **100** of FIG. **3** of a receiving wireless device.

The method **800** commences with the receiving wireless communication device receiving a preamble sequence from the transmitting wireless device and estimating a channel response (H) from the preamble sequence (step **802**). Techniques similar/same as those described with reference to step **702** of FIG. **7** may be employed.

The receiving wireless device then decomposes the channel response (H) based upon the receiver beamforming unitary matrix (U) to produce an estimated transmitter beamforming unitary matrix (V) (step **804**). With the estimated transmitter beamforming unitary matrix (V) determined, the receiving wireless device then decomposes the estimated transmitter beamforming unitary matrix (V) using a Givens Rotation to produce the transmitter beamforming information (step **806**). The products of this Givens Rotation are the transmitter beamforming information.

Operation continues with the receiving wireless device wirelessly sending the transmitter beamforming information to the transmitting wireless device (step **808**). This operation occurs with the receiving wireless device shifting to a transmit mode and sending the transmitter beamforming information to the transmitting wireless device. The transmitting wireless device then uses the feedback components to generate a new beamforming matrix (V), which it uses for subsequent transmissions (step **810**).

One example of a Givens Rotation matrix that may be used for the decomposition operations of step **806** (and step **708**) is:

$$G_l(\psi) = \begin{bmatrix} I_{l-1} & 0 & 0 & 0 \\ 0 & \cos\psi & \sin\psi & 0 \\ 0 & -\sin\psi & \cos\psi & 0 \\ 0 & 0 & 0 & I_{N-l-1} \end{bmatrix}$$

With this form, the Givens Rotation matrix rotates M [I,j], [I,j] to make (i,j−1)th component zero, where M [I,j],[I,j] is 2×2 block matrix at ith, jth row and ith, jth column.

Applying the Givens Rotation to the 2×2 estimated transmitter beamforming matrix (V) described above, for a particular form of the Givens Rotation, ψ in [0, π/2], ϕ in [−π, π] the 2×2 estimated transmitter beamforming matrix (V) can be rewritten as:

$$V = \begin{bmatrix} \cos\psi_1 & \cos\left(\frac{\pi}{2} - \psi_1\right) \\ \sin\psi_1 e^{j(\pi+\phi_2)} & \sin\left(\frac{\pi}{2} - \psi_1\right) e^{j\phi_2} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & e^{j\phi} \end{bmatrix} \begin{bmatrix} \cos\psi & \sin\psi \\ -\sin\psi & \cos\psi \end{bmatrix}$$

With angle resolution of $\pi/2^a$, where a=# of bits per angle, the total number of bits per tone is (a−1)+(a+1)=2a. With the 2×2 estimated transmitter beamforming matrix (V), ψ needs (a−1) bits to cover [0, π/2] and ϕ needs (a+1) bits to cover [−π, π]. With this notation: 'a=1' means quantized angle is either [π/4, 3π/4] to cover [0, π] angle resolution of π/2; and 'a=2' means quantized angle is either [π/8, 3π/8, 5π/8, 7π/8] to cover [0, π] with angle resolution of π/4.

By using all combinations of the Givens Rotation, these concepts may be extended to an N×M matrix. Because the Givens Rotation needs real values, a phase matrix Di is applied before the Givens Rotation to yield:

$$V = \prod_{i=1}^{M} \left[D_i(1_{i-1} e^{j\phi_{ii}} \ \dots \ e^{j\phi_{iN}}) \prod_{j=i}^{N-1} G_j(\psi_{i,j}) \right] \times \tilde{I}_{N\times M}$$

Where:

D_i is an N×N diagonal matrix with diagonal components in arguments.

$I_{N\times M}$ is an N×M identity matrix, where $(I)_{ii}=1$ for i=1, . . . , min(M,N).

As the reader will appreciate, the coefficients of the Givens Rotation and the phase matrix coefficients serve as the transmitter beamforming information that is sent from the receiving wireless communication device to the transmitting wireless communication device. For a 3×3 estimated transmitter beamforming matrix (V), from Givens Rotation, six angles in total (ϕ_{22}, ϕ_{23}, ϕ_{33}, ψ_{12}, ψ_{13}, ψ_{23}) are required. With angle resolution of $\pi/2^a$, where a=# of bits per angle, the total number of bits per tone is 3(a−1)+3(a+1)=6a. In such case, ψ needs (a−1) bits to cover [0, π/2] and ϕ needs (a+1) bits to cover [−π, π]. Using this polar coordinates embodiment, 24 bits per sub carrier are required to achieve equivalent full resolution performance to a Cartesian coordinates solution, which requires 72 bits per sub carrier.

For a 4×4 estimated transmitter beamforming matrix (V), from Givens Rotation, twelve angles in total (ϕ_{22}, ϕ_{23}, ϕ_{24}, ϕ_{33}, ϕ_{34}, ϕ_{44}, ψ_{12}, ψ_{13}, ψ_{23}, ψ_{23}, ψ_{24}, ψ_{33}) are required. With angle resolution of $\pi/2^a$, where a=# of bits per angle, the total number of bits per tone is 6(a−1)+6(a+1)=12a. In such case, ψ needs (a−1) bits to cover [0, π/2] and ϕ needs (a+1) bits to cover [−π, π]. Using this polar coordinates embodiment, 48 bits per sub carrier are required to achieve equivalent full resolution performance to a Cartesian coordinates solution, which requires 128 bits per sub carrier.

Using these techniques, for a simple case of 2×2 system with 20 MHz BW, the feedback of transmitter beamforming information requires 10*52/8=65 bytes. For the worst case of 4×4 system with 40 MHz BW (108 tones), the feedback requires 48*108/8=648 bytes. Efficiencies can be further obtained by using the correlation property of adjacent tones. (e.g., sending one information per every three tones). However, with a slowly fading channel, frequent channel feedback is not required.

The preceding discussion has presented a method and apparatus for reducing feedback information for beamforming in a wireless communication by using polar coordinates. As one of average skill in the art will appreciate, other embodiments may be derived from the present teachings without deviating from the scope of the claims.

What is claimed is:

1. A method for feeding back transmitter beamforming information from a receiving wireless communication device to a transmitting wireless communication device, the method comprising:

the receiving wireless communication device receiving a preamble sequence from the transmitting wireless device;

the receiving wireless device estimating a channel response based upon the preamble sequence;

the receiving wireless device determining an estimated transmitter beamforming unitary matrix (V) based upon the channel response and a receiver beamforming unitary matrix (U);

the receiving wireless device decomposing the estimated transmitter beamforming unitary matrix (V) to produce the transmitter beamforming information; and

the receiving wireless device wirelessly sending the transmitter beamforming information to the transmitting wireless device.

2. The method of claim **1** wherein the receiving wireless device determining an estimated transmitter beamforming unitary matrix (V) based upon the channel response and a receiver beamforming unitary matrix (U) comprises:

the receiving wireless device producing the estimated transmitter beamforming unitary matrix (V) in Cartesian coordinates; and

the receiving wireless device converting the estimated transmitter beamforming unitary matrix (V) to polar coordinates.

3. The method of claim **1** wherein the channel response (H), estimated transmitter beamforming unitary matrix (V), and the receiver beamforming unitary matrix (U) are related by the equation:

$$H=UDV^*$$

where, D is a diagonal matrix.

4. The method of claim **3**, wherein the receiving wireless device determining an estimated transmitter beamforming unitary matrix (V) based upon the channel response and a receiver beamforming unitary matrix (U) comprises performing a Singular Value Decomposition (SVD) operation.

5. The method of claim **1**, wherein the receiving wireless device decomposing the estimated transmitter beamforming unitary matrix (V) to produce the transmitter beamforming information comprises the receiving wireless device decomposing the estimated transmitter beamforming unitary matrix (V) using a QR decomposition technique.

6. The method of claim **5**, wherein the QR decomposition technique comprises a Givens Rotation operation performed according to the equation:

$$V = \prod_{i=1}^{M} \left[D_i(1_{i-1} e^{j\phi_{ii}} \ \dots \ e^{j\phi_{iN}}) \prod_{j=i}^{N-1} G_j(\psi_{i,j}) \right] \times \tilde{I}_{N\times M}$$

Where:

D_i is an N×N diagonal matrix with diagonal components in arguments;

$I_{N\times M}$ is an N×M identity matrix, where $(I)_{ii}=1$ for i=1, . . . , min(M,N); and

wherein the transmitter beamforming information includes angles corresponding to elements of the diagonal matrix D and elements of the Givens Rotation, wherein N is a number of transmit antennas, M is a number of receive antennas, and wherein i and j are each integers.

7. The method of claim **1**, wherein:

the transmitting wireless device transmits on N antennas; and

the receiving wireless device receives on M antennas.

8. The method of claim **1**, wherein at least one of the transmitting wireless device and the receiving wireless device supports Multiple Input Multiple Output (MIMO) operations.

9. A wireless communication device comprising:

a plurality of Radio Frequency (RF) components operable to receive an RF signal and to convert the RF signal to a baseband signal; and

a baseband processing module operable to:

receive a preamble sequence carried by the baseband signal;

estimate a channel response based upon the preamble sequence;

determine an estimated transmitter beamforming unitary matrix (V) based upon the channel response and a receiver beamforming unitary matrix (U);

decompose the estimated transmitter beamforming unitary matrix (V) to produce the transmitter beamforming information; and

form a baseband signal employed by the plurality of RF components to wirelessly send the transmitter beamforming information to the transmitting wireless device.

10. The wireless communication device of claim **9**, wherein in determining an estimated transmitter beamforming unitary matrix (V) based upon the channel response and a receiver beamforming unitary matrix (U), the baseband processing module is operable to:

produce the estimated transmitter beamforming unitary matrix (V) in Cartesian coordinates; and

convert the estimated transmitter beamforming unitary matrix (V) to polar coordinates.

11. The wireless communication device of claim **9**, wherein the channel response (H), estimated transmitter beamforming unitary matrix (V), and the receiver beamforming unitary matrix (U) are related by the equation:

$$H=UDV^*$$

where, D is a diagonal matrix.

12. The wireless communication device of claim **9**, wherein in determining the estimated transmitter beamforming unitary matrix (V) based upon the channel response and the receiver beamforming unitary matrix (U), the baseband processing module performs Singular Value Decomposition (SVD) operations.

13. The wireless communication device of claim **9**, wherein in decomposing the estimated transmitter beamforming unitary matrix (V) to produce the transmitter beamforming information, the baseband processing module decomposes the estimated transmitter beamforming unitary matrix (V) using a QR decomposition technique.

14. The wireless communication device of claim **13**, wherein the QR decomposition technique comprises a Givens Rotation operation performed according to the equation:

$$V=\prod_{i=1}^{M}\left[D_i(1_{i-1}e^{j\phi_{ii}}\ \dots\ e^{j\phi_{iN}})\prod_{j=i}^{N-1}G_j(\psi_{i,j})\right]\times\tilde{I}_{N\times M}$$

Where:

D_i is an N×N diagonal matrix with diagonal components in arguments;

$I_{N\times M}$ is an N×M identity matrix, where $(I)_{ii}=1$ for i=1, . . . , min(M,N); and

wherein the transmitter beamforming information includes angles corresponding to elements of the diagonal matrix D and elements of the Givens Rotation, wherein N is a number of transmit antennas, M is a number of receive antennas, and wherein i and j are each integers.

15. The wireless communication device of claim **10**, wherein:

the transmitting wireless device transmits on N antennas; and

the wireless communication device includes M antennas.

16. The wireless communication device of claim **10**, wherein the wireless communication device supports Multiple Input Multiple Output (MIMO) operations.

17. A method for feeding back transmitter beamforming information from a receiving wireless communication device to a transmitting wireless communication device, the method comprising:

the receiving wireless communication device receiving a preamble sequence from the transmitting wireless device;

the receiving wireless device estimating a channel response based upon the preamble sequence;

the receiving wireless device decomposing the channel response based upon the channel response and a receiver beamforming unitary matrix (U) to produce an estimated transmitter beamforming unitary matrix (V);

the receiving wireless device decomposing the estimated transmitter beamforming unitary matrix (V) to produce the transmitter beamforming information; and

the receiving wireless device wirelessly sending the transmitter beamforming information to the transmitting wireless device.

18. The method of claim **17**, wherein the receiving wireless device decomposing the channel response based upon the channel response and a receiver beamforming unitary matrix (U) to produce an estimated transmitter beamforming unitary matrix (V) includes performing a Singular Value Decomposition (SVD) operation.

19. The method of claim **17**, wherein the receiving wireless device decomposing the estimated transmitter beamforming unitary matrix (V) to produce the transmitter beamforming information comprises the receiving wireless device decomposing the estimated transmitter beamforming unitary matrix (V) using a Givens Rotation operation performed according to the equation:

$$V=\prod_{i=1}^{M}\left[D_i(1_{i-1}e^{j\phi_{ii}}\ \dots\ e^{j\phi_{iN}})\prod_{j=i}^{N-1}G_j(\psi_{i,j})\right]\times\tilde{I}_{N\times M}$$

Where:

D_i is an N×N diagonal matrix with diagonal components in arguments;

$I_{N \times M}$ is an N×M identity matrix, where $(I)_{ii}=1$ for i=1, . . . , min(M,N); and

wherein the transmitter beamforming information includes angles corresponding to elements of the diagonal matrix D and elements of the Givens Rotation, wherein N is a number of transmit antennas, M is a number of receive antennas, and wherein i and j are each integers.

20. The method of claim **19**, wherein the transmitter beamforming information comprises element values of the diagonal matrix D and element values of the Givens Rotation matrix.

* * * * *

Exhibit F

Matrix Computations

THIRD EDITION

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2.5 Orthogonality and the SVD

Orthogonality has a very prominent role to play in matrix computations. After establishing a few definitions we prove the extremely useful singular value decomposition (SVD). Among other things, the SVD enables us to intelligently handle the matrix rank problem. The concept of rank, though perfectly clear in the exact arithmetic context, is tricky in the presence of roundoff error and fuzzy data. With the SVD we can introduce the practical notion of numerical rank.

2.5.1 Orthogonality

A set of vectors $\{x_1, \ldots, x_p\}$ in $\mathbb{R}^m$ is *orthogonal* if $x_i^T x_j = 0$ whenever $i \neq j$ and *orthonormal* if $x_i^T x_j = \delta_{ij}$. Intuitively, orthogonal vectors are maximally independent for they point in totally different directions.

A collection of subspaces $S_1, \ldots, S_p$ in $\mathbb{R}^m$ is *mutually orthogonal* if $x^T y = 0$ whenever $x \in S_i$ and $y \in S_j$ for $i \neq j$. The *orthogonal complement* of a subspace $S \subseteq \mathbb{R}^m$ is defined by

$$S^\perp = \{y \in \mathbb{R}^m : y^T x = 0 \text{ for all } x \in S\}$$

and it is not hard to show that $\text{ran}(A)^\perp = \text{null}(A^T)$. The vectors $v_1, \ldots, v_k$ form an *orthonormal* basis for a subspace $S \subseteq \mathbb{R}^m$ if they are orthonormal and span S.

A matrix $Q \in \mathbb{R}^{m \times m}$ is said to be *orthogonal* if $Q^T Q = I$. If $Q = [\, q_1, \ldots, q_m \,]$ is orthogonal, then the q_i form an orthonormal basis for $\mathbb{R}^m$. It is always possible to extend such a basis to a full orthonormal basis $\{v_1, \ldots, v_m\}$ for $\mathbb{R}^m$:

Theorem 2.5.1 *If $V_1 \in \mathbb{R}^{n \times r}$ has orthonormal columns, then there exists $V_2 \in \mathbb{R}^{n \times (n-r)}$ such that*

$$V = [\, V_1 \; V_2 \,]$$

is orthogonal. Note that $\text{ran}(V_1)^\perp = \text{ran}(V_2)$.

Proof. This is a standard result from introductory linear algebra. It is also a corollary of the QR factorization that we present in §5.2. □

2.5.2 Norms and Orthogonal Transformations

The 2-norm is invariant under orthogonal transformation, for if $Q^TQ = I$, then $\| Qx \|_2^2 = x^TQ^TQx = x^Tx = \| x \|_2^2$. The matrix 2-norm and the Frobenius norm are also invariant with respect to orthogonal transformations. In particular, it is easy to show that for all orthogonal Q and Z of appropriate dimensions we have

$$\| QAZ \|_F = \| A \|_F \qquad (2.5.1)$$

and

$$\| QAZ \|_2 = \| A \|_2 . \qquad (2.5.2)$$

2.5.3 The Singular Value Decomposition

The theory of norms developed in the previous two sections can be used to prove the extremely useful singular value decomposition.

Theorem 2.5.2 (Singular Value Decomposition (SVD)) *If A is a real m-by-n matrix, then there exist orthogonal matrices*

$$U = [\, u_1, \ldots, u_m \,] \in \mathbb{R}^{m\times m} \quad \textit{and} \quad V = [\, v_1, \ldots, v_n \,] \in \mathbb{R}^{n\times n}$$

such that

$$U^TAV = \mathrm{diag}(\sigma_1, \ldots, \sigma_p) \in \mathbb{R}^{m\times n} \quad p = \min\{m, n\}$$

where $\sigma_1 \geq \sigma_2 \geq \ldots \geq \sigma_p \geq 0$.

Proof. Let $x \in \mathbb{R}^n$ and $y \in \mathbb{R}^m$ be unit 2-norm vectors that satisfy $Ax = \sigma y$ with $\sigma = \| A \|_2$. From Theorem 2.5.1 there exist $V_2 \in \mathbb{R}^{n\times(n-1)}$ and $U_2 \in \mathbb{R}^{m\times(m-1)}$ so $V = [\, x \;\; V_2 \,] \in \mathbb{R}^{n\times n}$ and $U = [\, y \;\; U_2 \,] \in \mathbb{R}^{m\times m}$ are orthogonal. It is not hard to show that U^TAV has the following structure:

$$U^TAV = \begin{bmatrix} \sigma & w^T \\ 0 & B \end{bmatrix} \equiv A_1 .$$

Since

$$\left\| A_1 \left(\begin{bmatrix} \sigma \\ w \end{bmatrix} \right) \right\|_2^2 \geq (\sigma^2 + w^Tw)^2$$

we have $\| A_1 \|_2^2 \geq (\sigma^2 + w^Tw)$. But $\sigma^2 = \| A \|_2^2 = \| A_1 \|_2^2$, and so we must have $w = 0$. An obvious induction argument completes the proof of the theorem. □

The σ_i are the *singular values* of A and the vectors u_i and v_i are the ith *left singular vector* and the ith *right singular vector* respectively. It

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is easy to verify by comparing columns in the equations $AV = U\Sigma$ and $A^TU = V\Sigma^T$ that

$$\left.\begin{aligned} Av_i &= \sigma_i u_i \\ A^T u_i &= \sigma_i v_i \end{aligned}\right\} \; i = 1{:}\min\{m, n\}$$

It is convenient to have the following notation for designating singular values:

$$\begin{aligned} \sigma_i(A) &= \text{the } i\text{th largest singular value of } A, \\ \sigma_{max}(A) &= \text{the largest singular value of } A, \\ \sigma_{min}(A) &= \text{the smallest singular value of } A. \end{aligned}$$

The singular values of a matrix A are precisely the lengths of the semi-axes of the hyperellipsoid E defined by $E = \{ Ax : \| x \|_2 = 1 \}$.

Example 2.5.1

$$A = \begin{bmatrix} .96 & 1.72 \\ 2.28 & .96 \end{bmatrix} = U\Sigma V^T = \begin{bmatrix} .6 & -.8 \\ .8 & .6 \end{bmatrix} \begin{bmatrix} 3 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} .8 & .6 \\ .6 & -.8 \end{bmatrix}^T .$$

The SVD reveals a great deal about the structure of a matrix. If the SVD of A is given by Theorem 2.5.2, and we define r by

$$\sigma_1 \ge \cdots \ge \sigma_r > \sigma_{r+1} = \cdots = \sigma_p = 0,$$

then

$$\begin{aligned} \text{rank}(A) &= r && (2.5.3) \\ \text{null}(A) &= \text{span}\{v_{r+1}, \ldots, v_n\} && (2.5.4) \\ \text{ran}(A) &= \text{span}\{u_1, \ldots, u_r\}\,, && (2.5.5) \end{aligned}$$

and we have the *SVD expansion*

$$A = \sum_{i=1}^{r} \sigma_i u_i v_i^T . \qquad (2.5.6)$$

Various 2-norm and Frobenius norm properties have connections to the SVD. If $A \in \mathbb{R}^{m\times n}$, then

$$\begin{aligned} \| A \|_F^2 &= \sigma_1^2 + \cdots + \sigma_p^2 \qquad p = \min\{m, n\} && (2.5.7) \\ \| A \|_2 &= \sigma_1 && (2.5.8) \end{aligned}$$

$$\min_{x\neq 0} \frac{\| Ax \|_2}{\| x \|_2} = \sigma_n \qquad (m \ge n) . \qquad (2.5.9)$$

LAPACK: Unsymmetric Eigenproblem	
_GEBAL	Balance transform
_GEBAK	Undo balance transform
_GEHRD	Hessenberg reduction $U^H AV = H$
_ORMHR	U (factored form) times matrix (real case)
_ORGHR	Generates U (real case)
_UNMHR	U (factored form) times matrix (complex case)
_UNGHR	Generates U (complex case)
_HSEQR	Schur decomposition of Hessenberg matrix
_HSEIN	Eigenvectors of Hessenberg matrix by inverse iteration
_GEES	Schur decomp of general matrix with e.value ordering
_GEESX	Same but with condition estimates
_GEEV	Eigenvalues and left and right eigenvectors of general matrix
_GEEVX	Same but with condition estimates
_TREVC	Selected eigenvectors of upper quasitriangular matrix
_TRSNA	Cond. estimates of selected eigenvalues of upper quasitriangular matrix
_TREXC	Unitary reordering of Schur decomposition
_TRSEN	Same but with condition estimates
_TRSYL	Solves $AX + XB = C$ for upper quasitriangular A and B

LAPACK: Unsymmetric Generalized Eigenproblem	
_GGBAL	Balance transform
_GGHRD	Reduction to Hessenberg-Triangular form
_HGEQZ	Generalized Schur decomposition
_TGEVC	Eigenvectors
_GGBAK	Undo balance transform

7.1 Properties and Decompositions

In this section we survey the mathematical background necessary to develop and analyze the eigenvalue algorithms that follow.

7.1.1 Eigenvalues and Invariant Subspaces

The *eigenvalues* of a matrix $A \in \mathbb{C}^{n\times n}$ are the n roots of its *characteristic polynomial* $p(z) = \det(zI - A)$. The set of these roots is called the *spectrum* and is denoted by $\lambda(A)$. If $\lambda(A) = \{\lambda_1, \ldots, \lambda_n\}$, then it follows that

$$\det(A) = \lambda_1\lambda_2\cdots\lambda_n .$$

Moreover, if we define the *trace* of A by

$$\mathrm{tr}(A) = \sum_{i=1}^{n} a_{ii},$$

then $\mathrm{tr}(A) = \lambda_1 + \cdots + \lambda_n$. This follows by looking at the coefficient of z^{n-1} in the characteristic polynomial.

If $\lambda \in \lambda(A)$, then the nonzero vectors $x \in \mathbb{C}^n$ that satisfy

$$Ax = \lambda x$$

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7.1.2 Decoupling

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Lemma 7.1.1 *If $T \in \mathbb{C}^n$*

then $\lambda(T) = \lambda(T_{11}) \cup \lambda(T$

Proof. Suppose

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where $x_1 \in \mathbb{C}^p$ and $x_2 \in$
$\lambda(T_{22})$. If $x_2 = 0$, then
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are referred to as *eigenvectors*. More precisely, x is a *right eigenvector* for λ if $Ax = \lambda x$ and a *left eigenvector* if $x^H A = \lambda x^H$. Unless otherwise stated, "eigenvector" means "right eigenvector."

An eigenvector defines a one-dimensional subspace that is invariant with respect to premultiplication by A. More generally, a subspace $S \subseteq \mathbb{C}^n$ with the property that

$$x \in S \Longrightarrow Ax \in S$$

is said to be *invariant* (for A). Note that if

$$AX = XB, \qquad B \in \mathbb{C}^{k \times k},\ X \in \mathbb{C}^{n \times k},$$

then ran(X) is invariant and $By = \lambda y \Rightarrow A(Xy) = \lambda(Xy)$. Thus, if X has full column rank, then $AX = XB$ implies that $\lambda(B) \subseteq \lambda(A)$. If X is square and nonsingular, then $\lambda(A) = \lambda(B)$ and we say that A and $B = X^{-1}AX$ are *similar*. In this context, X is called a *similarity transformation*.

7.1.2 Decoupling

Many eigenvalue computations involve breaking the given problem down into a collection of smaller eigenproblems. The following result is the basis for these reductions.

Lemma 7.1.1 *If $T \in \mathbb{C}^{n \times n}$ is partitioned as follows,*

$$T = \begin{bmatrix} T_{11} & T_{12} \\ 0 & T_{22} \end{bmatrix} \begin{matrix} p \\ q \end{matrix}, \qquad \begin{matrix} p & q \end{matrix}$$

then $\lambda(T) = \lambda(T_{11}) \cup \lambda(T_{22})$.

Proof. Suppose

$$Tx = \begin{bmatrix} T_{11} & T_{12} \\ 0 & T_{22} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \lambda \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$$

where $x_1 \in \mathbb{C}^p$ and $x_2 \in \mathbb{C}^q$. If $x_2 \neq 0$, then $T_{22}x_2 = \lambda x_2$ and so $\lambda \in \lambda(T_{22})$. If $x_2 = 0$, then $T_{11}x_1 = \lambda x_1$ and so $\lambda \in \lambda(T_{11})$. It follows that $\lambda(T) \subset \lambda(T_{11}) \cup \lambda(T_{22})$. But since both $\lambda(T)$ and $\lambda(T_{11}) \cup \lambda(T_{22})$ have the same cardinality, the two sets are equal. □

7.1.3 The Basic Unitary Decompositions

By using similarity transformations, it is possible to reduce a given matrix to any one of several canonical forms. The canonical forms differ in how they display the eigenvalues and in the kind of invariant subspace information that they provide. Because of their numerical stability we begin by discussing the reductions that can be achieved with unitary similarity.

EXHIBIT D

UNITED STATES DISTRICT COURT

SOUTHERN DISTRICT OF CALIFORNIA

BELL NORTHERN RESEARCH, LLC, Plaintiff, v. COOLPAD TECHNOLOGIES, INC. AND YULONG COMPUTER COMMUNICATIONS, Defendants.	Case No. 3:18-cv-01783-CAB-BLM [LEAD CASE]
BELL NORTHERN RESEARCH, LLC, Plaintiff, v. HUAWEI DEVICE (DONGGUAN) CO., LTD., HUAWEI DEVICE (SHENZHEN) CO., LTD., and HUAWEI DEVICE USA, INC., Defendants.	Case No. 3:18-cv-01784-CAB-BLM

BELL NORTHERN RESEARCH, LLC, Plaintiff, v. KYOCERA CORPORATION and KYOCERA INTERNATIONAL INC., Defendants.	Case No. 3:18-cv-01785-CAB-BLM
BELL NORTHERN RESEARCH, LLC, Plaintiff, v. ZTE CORPORATION, ZTE (USA) INC., ZTE (TX) INC., Defendants.	Case No. 3:18-cv-01786-CAB-BLM

REBUTTAL DECLARATION OF PAUL MIN, PH.D.
REGARDING CLAIM CONSTRUCTION

I certify under penalty of perjury that the following is true and correct.

Date: May 8, 2019 By: ______________________________
Paul Min, Ph.D.

TABLE OF CONTENTS

PAGE

I. Introduction

1. My name is Paul Min, Ph.D. I am a Senior Professor of Electrical and Systems Engineering at Washington University in St. Louis, Missouri. I am over the age of twenty-one, competent to make this declaration, and have personal knowledge of the matters stated herein.

2. I have been retained on behalf of Defendants Kyocera Corporation and Kyocera International Inc. ("Kyocera Defendants) to opine on and provide expert testimony related to: (i) U.S. Patent No. 6,941,156 ("the '156 Patent"), and (ii) U.S. Patent No. 7,957,450 ("the '450 Patent"), and (iii) U.S. Patent No. 8,416,862 ("the '862 Patent"). I understand that my opinions and expert testimony are also relevant to proceedings involving one or more of these three patents with respect to Defendants Coolpad Technologies, Inc. and Yulong Computer Communications ("Coolpad Defendants"); Huawei Device (Dongguan) Co., Ltd., Huawei Device (Shenzhen) Co., Ltd., Huawei Device USA, Inc., ("Huawei Defendants"); and ZTE Corporation, ZTE (USA) Inc., and ZTE (TX) Inc. ("ZTE Defendants"), whose cases have been consolidated with the Kyocera Defendants for claim construction purposes. For purposes of this statement, the term "Defendants" is used to generally refer to the Kyocera Defendants, Coolpad Defendants, Huawei Defendants, and ZTE Defendants.

3. On May 1, 2019, I submitted the Declaration of Paul Min, Ph.D. Regarding Claim Construction ("Opening Declaration"). I have been asked to review and respond to opinions presented in the Amended Opening Declaration of Dr. Vijay K. Madisetti, Ph.D. In Support Of Plaintiff's Claim Constructions dated May 2, 2019 ("Madisetti") with respect to the '156 Patent, '450 Patent, and '862 Patent ("Patents-in-Suit") in this declaration.

4. To prepare this declaration, I have reviewed and considered the opinions expressed in the Madisetti Declaration, the specification, claims, and prosecution histories of the Patents-in-Suit, as well as the extrinsic evidence identified in the Madisetti Declaration.

5. This declaration is based on the information currently available to me. To the extent additional information becomes available, I reserve the right to amend and supplement this statement and my analysis and opinions. To the extent that Dr. Madisetti, or any other expert, provides testimony or evidence related to the scope and meaning of the ’156 Patent, ’450 Patent, and ’862 Patent, or to the extent that BNR amends its proposed constructions, I reserve the right to review and respond.

6. My understanding is that the Court will hold a claim construction hearing. If I am called upon to testify at this hearing or any other proceeding about this statement, including at deposition, I may cite other documents or information similar to that specifically identified in this statement. I may also use graphics, animations, pictures, demonstrations, and/or other audio/visual aids to explain my analysis and opinions.

7. My qualifications are set forth in my Opening Declaration.

8. For my time spent in connection with this declaration, I will be compensated in the amount of $450 per hour. My compensation does not depend on the outcome of this case.

II. Legal Principles for Claim Construction

9. Within this statement, I apply my understanding of certain legal standards to opine on the scope and meaning of certain disputed claim terms. However, I am not a lawyer or an expert in patent law. Following is my understanding of these legal standards.

10. My understanding is that a patent claim should be interpreted based on what it would mean to a POSITA as of the filing date of the patent. Among other information, the claim language and specification are relevant to determining the meaning of the patent claim. Because a claim is interpreted according to its meaning to a POSITA, the knowledge, education, and experience of a POSITA are also relevant to determining the scope and meaning of a patent claim.

11. A primary source for construing a claim term is the plain meaning to a POSITA of the claim term itself. My understanding is that the claims are to be construed from the terms as written. The language of the claims is not to be re-written through interpretation. Other claims in the patent can also be informative, because claim terms are normally used consistently throughout the patent. It is also my understanding that language in a claim should not be construed so as to render claim language superfluous.

12. I understand that claims are read in light of the specification as understood by a POSITA. One should look to the specification and other intrinsic evidence for assistance in understanding a claim term because a patentee may have ascribed a particular meaning to a term. However, unless stated otherwise in the patent document or prosecution history, it is my understanding that limitations from the specification generally should not be read into the claims.

13. I also understand that the prosecution history of a patent provides the record of the examination of a patent application before the U.S. Patent and Trademark Office (PTO). The prosecution history provides evidence of how the patent examiner and the inventor understood the patent application and the claims, and can therefore be instructive on how to interpret the claims. It is my understanding that arguments or amendments made concerning one patent

application can be instructive as to the meaning of like terms in another related patent application.

14. My understanding is that there are at least two circumstances where the words in a patent claim may differ from and not be given their plain and ordinary meaning. One circumstance is when the applicants act as their own lexicographer by clearly setting forth a definition of a claim term that may differ from the plain and ordinary meaning it would otherwise possess. Another circumstance is when the applicant includes or provides an intentional disclaimer, or disavowal, of claim scope. My understanding is that an applicant may act as their own lexicographer, or disclaim or disavow claim scope, in either the specification or the prosecution history of the patent. My understanding is also that the applicant may act as a lexicographer, or disclaim or disavow claim scope, by making amendments to the claims during prosecution, or by making assertions to the PTO about the differences between the claimed inventions and the prior art.

15. My understanding is that extrinsic evidence may also be used in understanding the meaning of a claim term. Extrinsic evidence includes dictionaries, treatises, expert testimony, and prior art. But it is my understanding that one should first look to the intrinsic evidence in construing claims.

16. My understanding is that a patent claim element can be expressed in so-called "means-plus-function" format. When expressed in this format, the claim will recite "means" for performing a specified function. In order to interpret and construe the meaning of a claim element in this format, my understanding is that the first step is to identify the recited function of the claim element. The second step is to refer to the specification, identifying any structure that the specification discloses and links to performing the claimed function. This structure should be sufficient to perform the claimed function.

17. My understanding is that a claim term is to be construed as a means-plus-function term even if it does not use the word "means," if the term (a) fails to recite sufficiently definite structure or (b) recites function without reciting sufficient structure for performing that function. I further understand that generic terms such as "mechanism," "element," "device," "module," and other nonce words are tantamount to using the word "means" because they typically do not connote sufficiently definite structure.

18. My understanding is that if the specification fails to disclose adequate corresponding structure to perform the claimed function, the claim is indefinite. Where the claimed function for a means-plus-function element can only be performed by specialized software executed by a general purpose computer, the specification must disclose an algorithm for performing the claimed function. I understand that if the specification fails to disclose an algorithm, the claim is indefinite for failure to disclose sufficient structure.

19. My understanding is that a patent claim is indefinite if the claim fails to inform, with reasonable certainty, those skilled in the art about the scope of the invention, when the claim is read in light of the specification delineating the patent and the prosecution history.

III. The '156 Patent

A. Person of Ordinary Skill in the Art ("POSITA")

20. Dr. Madisetti states that a POSITA would "have a bachelor's degree in electrical engineering, computer engineering, computer science or similar field, and two to three years of experience in digital communications systems, such as wireless communications systems and networks, or equivalent." Madisetti ¶ 45. I provided a similar opinion. Opening Declaration ¶ 73. Under either definition, however, my opinions in this declaration and in my Opening Declaration remain the same.

B. Construction of the Disputed Terms in the '156 Patent

21. I have reviewed and considered Dr. Madisetti's opinion on the meaning of the disputed terms of the '156 Patent in view of the specification, claims, and prosecution history (including the Schellinger prior art patent cited therein). I disagree with Dr. Madisetti's opinions regarding the proper construction of the disputed terms in the '156 Patent from the perspective of a POSITA, as explained below. References to the perspective of a POSITA in this section are at the time of filing of the '156 Patent identified in my opening declaration.

a. *"simultaneous communication paths from said multimode cell phone"*

'156 Patent Claim Term	BNR's Proposed Construction	Defendants' Proposed Construction
"simultaneous communication paths from said multimode cell phone"	Plain and ordinary meaning. In the alternative, to the extent the Court determines that a specific construction is warranted, BNR proposes: "two or more active links at the same time from said multimode cellphone"	"at least two established distinct and different communication links from said multimode cell phone to a far-end communication device, at the same time"

Joint Claim Construction Worksheet, Appendix A at 34–35.

22. In paragraph 49, Dr. Madisetti states that "two simultaneous communication paths (labeled 1st and 2nd) are represented as **active**" in Figure 1. Dr. Madisetti cites to Figure 1 and the specification at column 4, lines 12 through 27 to support his statement. Based on my review, neither Figure 1 nor the cited passages in column 4 state that these "paths" are "active." Dr. Madisetti fails to explain the

meaning of the term "active," and the specification does not disclose its meaning in this context either. To a POSITA, an active link could mean a link maintaining transmission and reception of data or an active link also could mean a link simply maintaining the connected state without transmitting and receiving data. A POSITA would have known that a multimode cell phone could be connected to another device without exchanging data for a certain period of time before it is timed out. Defendants' proposed construction avoids this ambiguity by construing the two paths as "distinct and different communication links." In my opinion, a POSITA would understand that Figure 1 illustrates that the "initial telephone call" and the "handed over telephone call" are on "distinct and different communication links" from the multimode cell phone to a "far-end communication device" (telephone 150).

23. In paragraph 51, Dr. Madisetti states that "Figure 1 shows clearly that the two active links that are active . . ." Again, Dr. Madisetti fails to explain what "active" means. Moreover, Dr. Madisetti's conclusion that "active links" are "active" adds further uncertainty to BNR's proposed construction. For example, it is uncertain whether the boundaries of BNR's proposed construction of the term "simultaneous communication paths" encompasses "active links" that are not in an active state (e.g., in a connected state without transmitting and receiving data, etc.).

24. In paragraph 51, Dr. Madisetti also states that "there does not need to be two simultaneous links which are active at the far end device." To support this conclusion, Dr. Madisetti relies on Figure 1 and a passage from the specification which states that the far end device can be "multi-mode or single mode." From this, Dr. Madisetti concludes that "it would not be possible for two links to simultaneously exist at the far end device" for single-mode devices. First, Dr. Madisetti fails to explain where the "active links" terminate based on BNR's

proposed construction. A POSITA would understand that a communication path must have two end-points. Second, Defendants' proposed construction is consistent with the specification which explains that Call Waiting may be used by a far end telephone (single-mode) device "to switch the far end telephone from one line to the other." Opening Declaration ¶ 85; *see also* '156 Patent, Abstract. Third, even if the far-end communication device is a single-mode telephone, such a device can receive two or more distinct and different communication links at the same time. For example, a single-mode telephone can have a call-waiting service and/or a three-way call service. These services involve having two or more communication links established at the single-mode telephone at the same time since these communication links in their entirety are distinct and different. Fourth, BNR's proposed construction of "two or more active links at the same time from said multimode cellphone" would encompass communication paths that terminate at the telephone network in a way that the applicant distinguished from the claims. During prosecution, the examiner rejected the original claims over Schellinger. A POSITA would understand that Schellinger discloses "two or more active links." The examiner confirmed this as well by stating that Schellinger disclosed establishing a second RF communication link "while said first RF communication link remains active":

> Regarding claim 4, Schellinger teaches a method of automatically switching between a first type RF communication link and a second type RF communication link different from said first type RF communication link, comprising:
>
> participating in said first type RF communication link (see Figs 7-1 and 7-2; and col. 6, ln 58-col. 8, ln 31);
>
> sensing an availability of said second type RF communication link (see Figs 7-1 and 7-2; and col. 6, ln 58-col. 8, ln 31);
>
> establishing said second type RF communication link while said first type RF communication link remains active (see Figs 7-1 and 7-2; and col. 6, ln 58-col. 8, ln 31); and
>
> switching parties participating in said first type RF communication link to active utilization of said second type RF communication link (see Figs 7-1 and 7-2; and col. 6, ln 58-col. 8, ln 31).

U.S. Patent Appl. No. 09/888,493, Dec. 8, 2004 Office Action (BNR-SDCA00000062). Schellinger Figure 1 is shown below:

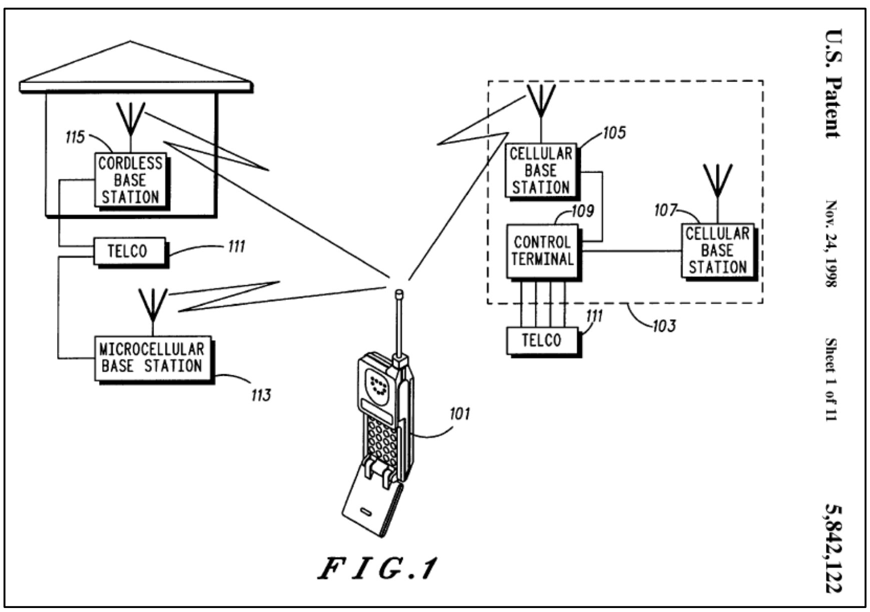


FIG.1

As explained in my opening declaration, the applicant amended the claims to distinguish the Schellinger prior art. Claim 1, for example, was amended to include "a module to establish simultaneous communication paths . . .":

> 1. (currently amended) A multimode cell phone, comprising:
>
> a cell phone functionality; and
>
> an RF communication functionality separate ~~, at least in part,~~ from said cell phone functionality;
>
> a module to establish simultaneous communication paths from said multimode cell phone using both said cell phone functionality and said RF communication functionality; and
>
> an automatic switch over module, in communication with both said cell phone functionality and said RF communication functionality, operable to switch a communication path established on one of said cell phone functionality and said RF communication functionality, with another communication path later established on the other of said cell phone functionality and said RF communication functionality.

U.S. Patent Appl. No. 09/888,493, Jan. 6, 2005 Response to Office Action (BNR-SDCA00000073). In distinguishing the amended claims from Schellinger, the applicant argued that Schellinger disclosed a "dual mode cellular cordless portable" phone, but that phone did not operate in "both [modes] simultaneously." The applicant also argued that Schellinger utilized a "three way call through the cellular telephone system" for the handoff (e.g., three paths to the telephone system from: a cellular communication path to the dual mode phone, a cordless communication path to the dual mode phone, and a communication path to the far end telephone). Thus, a POSITA would understand that the amended claims require a multimode cell phone having "communication paths" requiring: (a) the establishment of simultaneous communication paths from the multimode cell phone, and (b) that the communication paths may not be handed off utilizing the telephone system (e.g., three way call). To satisfy these conditions, a POSITA would understand that the claimed simultaneous communication paths from the multimode cell phone must necessarily terminate at the far end telephone, and not at the telephone system. A POSITA would understand that BNR's proposed construction does not satisfy these conditions because construing simultaneous communication paths to mean "two or more active links at the same time from said multimode cellphone" would encompass communication paths that terminate at the telephone system and that are handed off in the telephone system using a single communication path to the far end telephone, which the applicants explicitly distinguished.

25. Accordingly, I disagree with Dr. Madisetti's opinion. As stated in my opening declaration, it is my opinion that a POSITA would understand the term "simultaneous communication paths from said multimode cell phone" to mean "at least two established distinct and different communication links from said multimode cell phone to a far-end communication device, at the same time."

b. *"cell phone functionality"*

'156 Patent Claim Term	BNR's Proposed Construction	Defendants' Proposed Construction
"cell phone functionality"	Not a 112 ¶ 6 claim element – "cell phone functionality" is not a nonce word. Instead, cell phone functionality is itself sufficient structure. A POSA would know this is a cellular RF communication functionality well known in the art.	This is a 112 ¶ 6 claim element. <u>Function:</u> "cell phone" <u>Structure:</u> Indefinite for lack of corresponding structure in the patent specification. Huawei and Coolpad Defendants state alternatively, to the extent that the Court requires an identification of structure, the

’156 Patent Claim Term	BNR’s Proposed Construction	Defendants’ Proposed Construction
		cell phone 100a and corresponding antenna depicted in Fig. 1 are insufficient structure to perform the claimed function.

Joint Claim Construction Worksheet, Appendix A at 35–37.

26. In paragraph 84, Dr. Madisetti states that “the term ‘cell phone functionality’ informs a POSITA of the scope of the claim with reasonable certainty.” Dr. Madisetti does not provide the basis or reasons for this opinion, or the facts and data that he considered in reaching this opinion. Dr. Madisetti also does not provide an opinion on the scope or boundaries of the term “cell phone functionality.” As such, there is no basis for me to review the methodology he employed to reach this opinion. To the extent that Dr. Madisetti, or any other expert, provides subsequent testimony or evidence related to the meaning of the term “cell phone functionality,” I reserve the right to respond.

27. Accordingly, I disagree with Dr. Madisetti’s opinion. As stated in my opening declaration, it is my opinion that a POSITA would understand that the “cell phone functionality” term is indefinite for lack of structure to perform the “cell phone” function.

c. *“RF communication functionality”*

’156 Patent Claim Term	BNR’s Proposed Construction	Defendants’ Proposed Construction
“RF communication functionality”	Not a 112 ¶ 6 claim element – “RF communication functionality” is not a	This is a 112 ¶ 6 claim element.

'156 Patent Claim Term	**BNR's Proposed Construction**	**Defendants' Proposed Construction**
	nonce word. Instead, RF communication functionality is itself sufficient structure. A POSA would know this is a structure for RF communications through a genus of RF communication types well known in the art.	Function: "RF communication" Structure: Indefinite for lack of corresponding structure in the patent specification. Huawei and Coolpad Defendants state alternatively, to the extent that the Court requires an identification of structure, any of the cordless phone 100b with its corresponding antenna and the walkie-talkie 100c with its corresponding antenna, are insufficient structure to perform the claimed function.

Joint Claim Construction Worksheet, Appendix A at 38–40.

28. In paragraph 86, Dr. Madisetti states that "the term 'RF communication functionality' informs a POSITA of the scope of the claim with reasonable certainty." Dr. Madisetti does not provide the basis or reasons for this opinion, or the facts and data that he considered in reaching this opinion. Dr. Madisetti also does not provide an opinion on the scope or boundaries of the term "RF communication functionality." As such, there is no basis for me to review the methodology he employed to reach this opinion. To the extent that Dr. Madisetti, or any other expert, provides subsequent testimony or evidence related to the meaning of the term "cell phone functionality," I reserve the right to respond.

29. Accordingly, I disagree with Dr. Madisetti's opinion. As stated in my opening declaration, it is my opinion that a POSITA would understand that the "RF communication functionality" term is indefinite for lack of structure to perform the "RF communication" function.

d. *"a module to establish simultaneous communication paths from said multimode cell phone using both said cell phone functionality and said RF communication functionality"*

'156 Patent Claim Term	BNR's Proposed Construction	Defendants' Proposed Construction
"a module to establish simultaneous communication paths from said multimode cell phone using both said cell phone functionality and said RF communication functionality"	Not a 112 ¶ 6 claim element – "module" is not a nonce word here. Instead, the "module to establish simultaneous communication paths from said multimode cell phone using both said cell phone functionality and said RF communication functionality" is itself sufficient structure. A POSA would know this is a structure for RF communications through a genus of RF communication types well known in the art. In the alternative, to the extent the Court determines that this claim is governed by 112 ¶ 6, BNR proposes the	This is a 112 ¶ 6 claim element.

'156 Patent Claim Term	BNR's Proposed Construction	Defendants' Proposed Construction
	following Function and Structure, and disagrees that the term is indefinite for lack of corresponding structure: Function: establish simultaneous communication paths from said multimode cell phone using both said cell phone functionality and said RF communication functionality Structure: Corresponding structure for the alleged function exists in at least the following portions of the patent specification, or their equivalents: Figs. 1, 3, Col. 3:48–4:49; 4:54–5:62; 6:3–55; 6:60–8:5	Function: "establish simultaneous communication paths from said multimode cell phone using both said cell phone functionality and said RF communication functionality" Kyocera & ZTE propose: Structure: Indefinite for lack of corresponding structure in the patent specification. Huawei & Coolpad propose: Structure: Fig. 1 (element 101); Fig. 2 steps 202-208; Fig. 4 steps 402-408; 4:50-67; 7:1-16.

Joint Claim Construction Worksheet, Appendix A at 38–40.

(1) This Term Is A Means-Plus-Function Term

30. Dr. Madisetti states that the "module to establish simultaneous communication paths" term is not a means-plus-function term. Madisetti ¶¶ 56–57. I disagree.

31. In paragraph 58, Dr. Madisetti states that the "module to establish simultaneous communication paths" term "refers to a class of structures within multimode cell phones that negotiate and control each of the modes of communication, namely cellular, RF communication (other than cellular) including piconet, walkie-talkie, and such genus of RF communication." Dr. Madisetti refers to "a class of structures," but fails to identify or provide examples of any such specific structures known to a POSITA for establishing simultaneous communication paths. In my opinion, at the time of the filing of the '156 Patent, the term "module to establish simultaneous communication paths" was not a term commonly used by POSITAs to describe structure or a "class of structures" for performing the claimed functionality.

32. In paragraph 59, Dr. Madisetti states that "cellular, wireless, cordless and related piconet technologies" were "well-known modes of communication." Dr. Madisetti states these modes "are related to the transceivers for each mode," as illustrated in Figure 1. Dr. Madisetti provides no analysis or explanation as to the relationship between "transceivers for each mode" and the structure (or class of structures) for a "module to establish simultaneous communication paths" term.

33. In paragraph 60, Dr. Madisetti states that "these modes" are "enabled and controlled by **hardware and software** within a multimode cell phone, and the interaction between each was understood in the art to be through **integrated circuitry (including hardware and software)** interacting with the transceivers." In my opinion, a POSITA would understand that "hardware and software" is a general term used to refer to electrical components and circuitry (e.g., RF, digital, analog, etc.), including general purpose computers (e.g., microprocessor, DSP, microcontroller, etc.) with specialized software programming. In my opinion, a

POSITA would not recognize "integrated circuitry (including hardware and software)" as identifying a definite class of structures.

34. Furthermore, Dr. Madisetti states that the "class of structures" (e.g., "hardware and software") is used to "negotiate and control each of the modes of communication." In my opinion, a POSITA would understand that this statement is a functional description of the alleged structure, not a description of the structure for performing the "negotiate and control" functions.

35. Accordingly, I disagree with Dr. Madisetti's opinion. As stated in my opening declaration, it is my opinion that a POSITA would understand that the term "module" is used in the claim as a nonce word. The term "module" is not structure nor does it recite sufficient structure to "establish simultaneous communication paths . . ." As such, I understand that the term "a module to establish simultaneous communication paths from said multimode cell phone using both said cell phone functionality and said RF communication functionality" must be construed as a means-plus-function term.

(2) This MPF Term Fails To Disclose Algorithms That Define Adequate Structure

36. In paragraph 62, Dr. Madisetti notes that if the term is construed to be a means-plus-function term, the parties agree on the function recited by the term.

37. In paragraph 63, Dr. Madisetti states that the structure for performing the recited function is "disclosed as the multimode cellular phone 100 in Figure 1, including the transceivers and related hardware and software components of 100a and 100b of multimode cellular phone 100 which also connects [sic] to one skilled in the art that there is a structure that is circuitry (**including hardware and software**) that controls, based on described inputs, produces certain outputs based on certain types of calculations, and also describes where the information travels

next." I disagree. A POSITA would understand that the disclosure relied upon by Dr. Madisetti (e.g., "circuitry (including hardware and software)") fails to identify sufficient structure to perform the claimed function. For example, a POSITA would understand that "circuitry (including hardware and software") to perform the claimed function includes a general purpose computer (e.g., microprocessor) programmed to perform the "establish simultaneous communication paths . . ." function.

38. Dr. Madisetti fails to identify an algorithm disclosed by the '156 Patent that explains how the "establish simultaneous communication paths . . ." function is to be performed by a general purpose computer. For example, in paragraph 64, Dr. Madisetti states that the module "controls each of the transceivers," but fails to identify an algorithm or structure for such control. In paragraph 65, Dr. Madisetti states that "components" are used for "establishing communication paths," but fails to identify an algorithm or specific components for doing so. In paragraph 66, Dr. Madisetti states that the specification describes a "last number dialed functionality" and a "lookup table" for tracking communication paths, but fails to identify an algorithm or structure for such functionality and tables. Dr. Madisetti states that a "lookup table" "would be used to identify which communication paths to switch between," however, switching communication paths refers to a different limitation (i.e., the "automatic switch over module" limitation) and therefore fails to identify an algorithm or structure for establishing the simultaneous communication paths. As explained in my opening declaration, it is my opinion that a POSITA would understand that the specification fails to disclose an algorithm for performing the "establish simultaneous communication paths . . ." function.

39. Accordingly, I disagree with Dr. Madisetti's opinion. As stated in my opening declaration, it is my opinion that a POSITA would understand that the "a

module to establish simultaneous communication paths from said multimode cell phone using both said cell phone functionality and said RF communication functionality" term is indefinite for lack of structure to perform the "establish simultaneous communication paths . . ." function.

e. ***"an automatic switch over module, in communication with both said cell phone functionality and said RF communication functionality, operable to switch a communication path established on one of said cell phone functionality and said RF communication functionality, with another communication path later established on the other of said cell phone functionality and said RF communication functionality"***

'156 Patent Claim Term	**BNR's Proposed Construction**	**Defendants' Proposed Construction**
"an automatic switch over module, in communication with both said cell phone functionality and said RF communication functionality, operable to switch a communication path established on one of said cell phone functionality and said RF communication functionality, with	Not a 112 ¶ 6 claim element – "module" is not a nonce word here. Instead, the "an automatic switch over module, in communication with both said cell phone functionality and said RF communication functionality, operable to switch a communication path established on one of said cell phone functionality and said RF communication functionality, with another communication path later	This is a 112 ¶ 6 claim element.

'156 Patent Claim Term	BNR's Proposed Construction	Defendants' Proposed Construction
another communication path later established on the other of said cell phone functionality and said RF communication functionality"	established on the other of said cell phone functionality and said RF communication functionality" is itself sufficient structure. A POSA would know this is a structure for RF communications through a genus of RF communication types well known in the art. In the alternative, to the extent the Court determines that this claim is governed by 112 ¶ 6, BNR proposes the following Function and Structure, and disagrees that the term is indefinite for lack of corresponding structure: Function: in communication with both said cell phone functionality and said RF communication functionality, operable to switch a communication path established on one of said cell phone functionality and said RF communication	Kyocera & ZTE propose: Function: "in communication with both said cell phone functionality and said RF communication functionality, operable to switch a communication path established on one of said cell phone functionality and said RF communication functionality, with another communication path later established on the other of said cell phone functionality and said RF communication functionality" Structure: Indefinite for lack of corresponding structure in the patent specification. Huawei & Coolpad propose: Function: "automatic switch over of a communication path established on one of said

’156 Patent Claim Term	BNR’s Proposed Construction	Defendants’ Proposed Construction
	functionality, with another communication path later established on the other of said cell phone functionality and said RF communication functionality Structure: Corresponding structure for the alleged function exists in at least the following portions of the patent specification, or their equivalents: Figs. 1, 3, Col. 3:48–4:49; 4:54–5:62; 6:3–55; 6:60–8:5	cell phone functionality and said RF communication functionality, with another communication path later established on the other of said cell phone functionality and said RF communication functionality” Structure: Fig. 1 (element 101); Fig. 2 steps 210-212; Fig. 4 steps 410-412; 5:1-7; 7:17-26, claim 1 (“an automatic switch over module, in communication with both said cell phone functionality and said RF communication functionality”).

Joint Claim Construction Worksheet, Appendix A at 38–40.

(1) This Term Is A Means-Plus-Function Term

40. Dr. Madisetti states that the “automatic switch over module” term is not a means-plus-function term. Madisetti ¶¶ 75–76. I disagree.

41. In paragraph 76, Dr. Madisetti states that the “automatic switch over module” term “denotes a class of structures that control the radios in the known art of cellular telephone technology at the time of the invention, including integrated circuits and the like, and that the term here represents an inventive modification to those known structures.” Dr. Madisetti refers to “a class of structures,” but fails to

identify or provide examples of any such specific structures known to a POSITA as an "automatic switch over module." In my opinion, at the time of the filing of the '156 Patent, the term "automatic switch over module" was not a term commonly used by POSITAs to describe structure or a "class of structures" for performing the claimed functionality.

42. In paragraph 76, Dr. Madisetti states that each mode of a multimode cell phone is "enabled and controlled by **hardware and software** within a multimode cell phone, and the interaction between each was understood in the art to be through **integrated circuitry** interacting with the transceivers." In my opinion, a POSITA would understand that the terms "hardware and software" and "integrated circuitry" are general terms used to refer to electrical components and circuitry (e.g., RF, digital, analog, etc.), including general purpose computers (e.g., microprocessor, DSP, microcontroller, etc.) with specialized software programming. In my opinion, a POSITA would not recognize "hardware and software" or "integrated circuitry" as identifying a definite class of structures.

43. In paragraph 76, Dr. Madisetti also states that the "class of structures" (e.g., "hardware and software") from the "known art of cellular telephone technology" includes "integrated circuits and the like." A POSITA would understand that "integrated circuits and the like" is a general term used to refer to electrical components and circuitry (e.g., RF, digital, analog, etc.), including general purpose computers (e.g., microprocessor, DSP, microcontroller, etc.) with specialized software programming. In my opinion, a POSITA would not recognize "integrated circuits and the like" as identifying a definite class of structures.

44. In paragraph 76, Dr. Madisetti also states that the "class of structures" (e.g., "hardware and software") is used to "control the radios in the known art of cellular telephone technology at the time of the invention." In my opinion, a

POSITA would understand that this statement is a functional description of the alleged structure, not a description of the structure for performing the "control the radios" functionality.

45. In paragraph 76, Dr. Madisetti also states that the "automatic switch over module" term "represents an inventive modification to those known structures." Dr. Madisetti fails to identify the specific "known structures" that must be modified to perform the claimed "automatic switch over module" functionality. In my opinion, Dr. Madisetti's statement that there is a "modification" to "known structures" fails to recite sufficiently definite structure to perform the claimed functionality.

46. Accordingly, I disagree with Dr. Madisetti's opinion. As stated in my opening declaration, it is my opinion that a POSITA would understand that the term "module" is used in the context of "an automatic switch over module" as a nonce word. The term "module" is not structure. Neither the term "automatic switch over module" nor the language of the claim itself recite sufficient structure to perform "in communication with both said cell phone functionality and said RF communication functionality, operable to switch a communication path established on one of said cell phone functionality and said RF communication functionality, with another communication path later established on the other of said cell phone functionality and said RF communication functionality." As such, I understand that the term "an automatic switch over module, in communication with both said cell phone functionality and said RF communication functionality, operable to switch a communication path established on one of said cell phone functionality and said RF communication functionality, with another communication path later established on the other of said cell phone functionality and said RF communication functionality" must be construed as a means-plus-function term.

(2) This MPF Term Fails To Disclose Algorithms That Define Adequate Structure

47. In paragraph 78, Dr. Madisetti identifies the parties' proposed construction for the recited function for this means-plus-function term, but does not offer an analysis or opinion on any of the proposed recited functions. BNR and the Kyocera Defendants proposed identical language for the recited function. For purposes of the analysis herein, I will assume that this is the recited function.

48. In paragraph 79, Dr. Madisetti states that the structure for performing the recited function is "disclosed as the multimode cellular phone 100 in Figure 1, including the transceivers and related hardware and software components of 100a and 100b of multimode cellular phone 100 and the automatic switchover module 101 that is shown implemented within the **hardware and software** of the multimode cell phone." I disagree. A POSITA would understand that the disclosure relied upon by Dr. Madisetti (e.g., "hardware and software") fails to identify sufficient structure to perform the claimed function. For example, a POSITA would understand that "hardware and software" to perform the claimed function includes a general purpose computer (e.g., microprocessor) programmed to perform the recited function.

49. Dr. Madisetti fails to identify an algorithm disclosed by the '156 Patent that explains how the recited function is to be performed by a general purpose computer. For example, in paragraph 79, Dr. Madisetti states that a POSITA "would understand "which components would incorporate the inventive additional functionalities embodied in this claim," but fails to identify such components or an algorithm or structure to incorporate the "inventive additional functionalities" in such components. As explained in my opening declaration, it is my opinion that a POSITA would understand that the specification fails to disclose an algorithm for performing the recited function.

50. Accordingly, I disagree with Dr. Madisetti's opinion. As stated in my opening declaration, it is my opinion that a POSITA would understand that the "an automatic switch over module, in communication with both said cell phone functionality and said RF communication functionality, operable to switch a communication path established on one of said cell phone functionality and said RF communication functionality, with another communication path later established on the other of said cell phone functionality and said RF communication functionality" term is indefinite for lack of structure to perform the recited function.

IV. The '450 Patent

A. Person of Ordinary Skill in the Art ("POSITA")

51. Dr. Madisetti states that a POSITA would "have a bachelor's degree in electrical engineering, computer engineering, computer science or similar field, and two to three years of experience in digital communications systems, such as wireless communications systems and networks, or equivalent." Madisetti ¶ 129. I provided a similar opinion. Opening Declaration ¶ 138. Under either definition, however, my opinions in this declaration and in my Opening Declaration remain the same.

B. Construction of the Disputed Terms in the '450 Patent

52. I have reviewed and considered Dr. Madisetti's opinion on the meaning of the disputed terms of the '450 Patent in view of the specification, claims, and prosecution history. I disagree with Dr. Madisetti's opinions regarding the proper construction of the disputed terms in the '450 Patent, from the perspective of a POSITA, as explained below. References to the perspective of a POSITA in this section are at the time of filing of the '450 Patent identified in my opening declaration.

a. *"channel estimate matrices"; "matrix based on the/said plurality of channel estimates"*

’450 Patent Claim Term	BNR’s Proposed Construction	Defendants’ Proposed Construction
“channel estimate matrices”; “matrix based on the/said plurality of channel estimates”	Plain and ordinary meaning. In the alternative, to the extent the Court determines that a specific construction is warranted, BNR proposes: “one or more matrices that is based on an SVD decomposition of the estimates of the values of H(t)”	“matrix H_{est} for tones of different frequencies, where H_{est} contains estimates of the true values of H(t)”

Joint Claim Construction Worksheet, Appendix A at 22–28.

53. I agree with Dr. Madisetti that “Singular Value Decomposition (“SVD”) is a well-known mathematical concept from linear algebra.” *Id*. at ¶ 138. I discussed SVD in my Opening Declaration. Dr. Madisetti states that “SVD is a matrix decomposition method for reducing a matrix to its constituent parts to make certain subsequent matrix calculations easier.” *Id*. It is not clear what Dr. Madisetti meant by “certain subsequent calculations” and how the SVD make them easier. As explained in my Opening Declaration, the SVD theorem establishes that if *A* is a real m-by-n matrix, then *A* may be factored into the product of three other matrices: an orthogonal left singular matrix *U*, a diagonal singular value matrix, and an orthogonal right singular matrix V^T.[1] I have explained in my Opening Declaration,

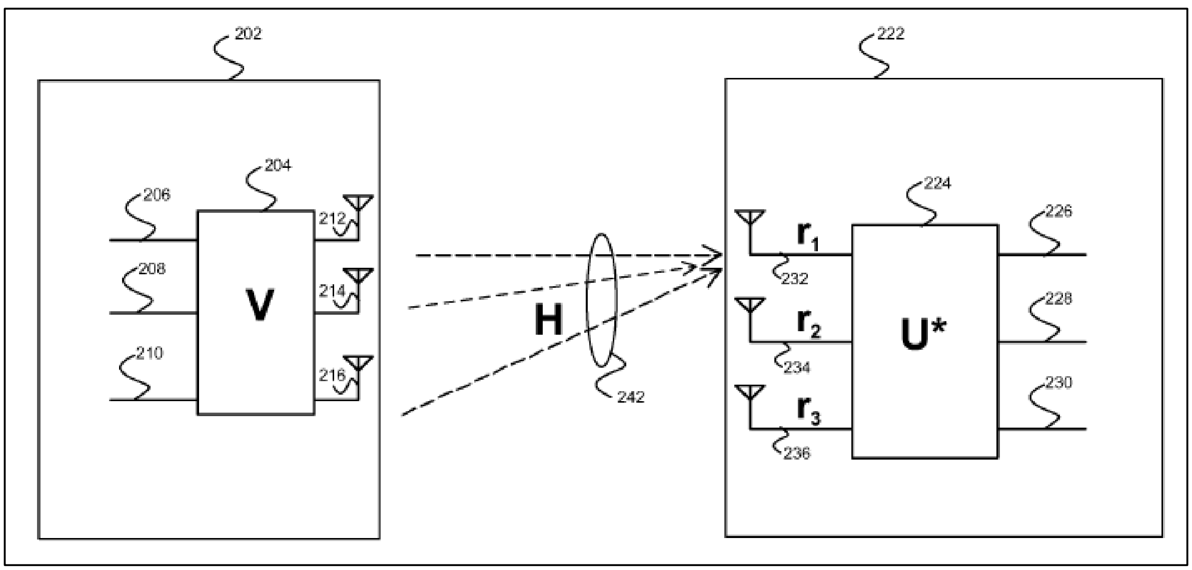
[1] V^T represents a transpose of the matrix *V*. The ’450 Patent uses the notation V^H to represent a transpose of the matrix *V*, where the “H” means it is a Hermitian transpose.

"the nonzero vectors $A \in C^n$ that satisfy $Ax = \lambda x$ are referred to as eigenvectors." Opening Declaration ¶¶ 42–54. A POSITA would have known that "$Ax = \lambda x$" means that the eigenvector "x" is an invariant subspace for the square matrix "A" and the corresponding eigenvalue "λ" characterizes the result of applying "A" to the invariant subspace corresponding to the eigenvector "x." I have also explained that "[i]n comparison, with regard to the singular value σ_i, Golub and Van Loan state that "$Av_i = \sigma_i u_i$ and $A^T u_i = \sigma_i v_i$ where i takes a value between 1 and $min \{m, n\}$." Opening Declaration ¶¶ 42–54. Analogous to the eigenvector/eigenvalue analysis for the square matrix, the SVD is used to characterize the invariant subspaces of a non-square matrix when the non-square matrix is multiplied to the left and right eigenvectors of the non-square matrix. This is the mathematical definition of the SVD and any ancillary use of SVD is not the purpose of the SVD itself, as Dr. Madisetti seems to suggest.

54. In paragraphs 139, Dr. Madisetti deviates from "the claim language" by using his own words to interpret the independent claims and conclude that the channel estimate matrices terms are "based on an SVD decomposition." *Id*. at ¶¶ 139–140. In doing so, Dr. Madisetti ignores the actual language of the claims. Claims 1 and 11 recite "a plurality of channel estimate matrices **based on signals received**." Claims 21 and 22 recite "a plurality of channel estimates **based on signals received**," and "[deriving/derive] a matrix **based on [the/said] plurality of channel estimates**." Thus, the language of the claims make clear to a POSITA that the channel estimate matrices are based on "signals received" (claims 1, 11) or "channel estimates" (claims 21, 22).

55. As explained in my Opening Declaration at ¶¶ 143–150, the '450 Patent consistently refers to a "channel estimate matrix" as a matrix H. For example, the specification states that a "[a] communications medium, such as a radio frequency

(RF) channel between a transmitting mobile terminal and a receiving mobile terminal," which a POSITA would understand to refer to a wireless communication channel, "may be represented by a transfer system function, H." *Id*. at 3:53–57. Each "H" matrix is further denoted as "H(t)," where "t" refers to a specific instant in time, because the channel (and the channel estimate) may vary as a function of time due to signal fading effects. '450 Patent, 4:5–9 ("In the case of fast fading, the transfer function, H, may itself become time varying and may thus also become a function of time, H(t)."). Figure 2 of the '450 Patent illustrates that "[t]he characteristics of the plurality of RF channels 242 utilized for communication between the transmitting mobile terminal 202, and the receiving mobile terminal 222 may be represented mathematically by a transfer coefficient matrix H." *Id*. at 11:61–65.



'450 Patent, Fig. 2.

56. In paragraph 139, Dr. Madisetti confirms that "channel estimate matrices" means one or more "H" matrices. Specifically, Dr. Madisetti states that "the method requires computing one or more **channel estimate matrices, H(t)** from

signals received by a wireless communication device from a base station." *Id*. at ¶ 137.

57. As explained in my Opening Declaration and above, SVD decomposes a matrix, such as a matrix H(t), into the product of three matrices, such as matrices U, S, and V^H. '450 Patent, 8:54 – 9:4 ("$H_{est}=USV^H$," as shown by equation [2]). A POSITA would know that the three matrices derived from SVD decomposition are not "channel estimate matrices." Instead, according to linear algebra, the three derived matrices represent factors of the claimed channel estimate matrix, and may be described as an orthogonal left singular matrix U, a diagonal singular value matrix S, and an orthogonal right singular matrix V^H.[2] *See also id*. at 8:57–9:4.

58. In paragraph 141, Dr. Madisetti states that the construction of the channel estimate matrices terms are wrong because "H_{est} or any other similar terms (for example, H_{up} and H_{down}) are never sent back. Only the results of a decomposition are transmitted back." Dr. Madisetti's analysis is incorrect. The claims do not recite transmitting back channel estimate matrices (i.e., H_{est}). Instead, the claims separately recite limitations for deriving "coefficients" and for transmitting the "coefficients as feedback information." Neither of these limitations change or redefine the meaning of the term "channel estimate matrices" or the term "matrix based on the/said plurality of channel estimates" to a POSITA based on the specification.

59. In paragraph 142, Dr. Madisetti objects to Defendants' proposed construction's use of the notation identifying the estimated channel estimate matrix H as H_{est}. However, H_{est} is the only notation from the specification that is used (i.e., "equation [2]") to describe a "full channel estimate matrix which is computed by a

[2] In algebra, factoring is used to identify factors of an expression that when multiplied together result in that expression. For example, the real number 24 may be factored into real numbers 2, 3, and 4, as shown by the equation: 24=2×3×4.

receiving mobile terminal, H_{est}, as required by the claim language. ’450 Patent, 8:52–65. No other notation is used in the context of the claim language. Dr. Madisetti contends that the claims should not exclude a matrix H_{up} and H_{down}. In the context of the specification, this notation is used to distinguish a “reverse channel estimate matrix, H_{up}” (for a channel where signals are received by a base station from a mobile terminal) from a “forward channel estimate matrix, H_{down}” (for a channel where signals are received by a mobile terminal from a base station). *Id*. at 4:66–5:7. However, the claim language specifically limits the channel estimate matrices “based on signals received by a mobile terminal from a base station” (i.e., signals received on a forward channel), and therefore, it is not necessary to use subscript notation to distinguish that the claimed channel estimate matrices are directed to the forward channel. And, just to be clear, a POSITA would understand that, in the context of the claim language, the matrix H_{est} refers to an estimate of a forward channel. Furthermore, the specification uses the H_{down} matrix notation in the context of embodiments not covered by the claim language in which a mobile terminal receives an H_{down} channel estimate matrix, rather than the receiving mobile terminal computing the channel estimate matrix:

> “To compensate for possible differences between H_{up} and H_{down} the receiving mobile terminal may be required to receive H_{down} from the transmitting mobile terminal, and to report $H_{up} - H_{down}$ as feedback information. ’450 Patent, 5:1–7.
>
> “In this aspect of the invention, **a receiving mobile terminal**, after transmitting a sounding frame, **may subsequently receive a channel estimate matrix, H_{down}, from the transmitting mobile terminal**.” *Id*. at 8:12–15.
>
> “In another embodiment of the invention, a calibration procedure may be performed between the transmitting mobile terminal and the receiving mobile terminal. In this case, **the transmitting**

mobile terminal may compute a full channel estimate matrix, H_{down}. The transmitting mobile terminal may transmit H_{down} to the receiving mobile terminal." *Id*. at 10:20–25.

"The MIMO channel request field 508 may also comprise information from the channel estimation matrix, **H_{down}, which is computed at the transmitting mobile terminal** 202. A receiving mobile terminal 222 that receives the MIMO channel request frame may use H_{down} information from the transmitting mobile terminal 202 to perform calibration." *Id*. at 14:46–49.

Thus, a POSITA would understand that Defendants' construction does not improperly exclude matrices from embodiments identified in the specification using the notation H_{up} and H_{down}.

60. Accordingly, I disagree with Dr. Madisetti's opinion. As stated in my opening declaration, it is my opinion that a POSITA would understand the terms "channel estimate matrices" and "matrix based on the/said plurality of channel estimates" to mean "matrix H_{est} for tones of different frequencies, where H_{est} contains estimates of the true values of H(t)."

b. "coefficients derived from performing a singular value matrix decomposition (SVD)"; "coefficients from performing a singular value matrix decomposition (SVD)"

'450 Patent Claim Term	**BNR's Proposed Construction**	**Defendants' Proposed Construction**
"coefficients derived from performing a singular value matrix decomposition (SVD)";	Plain and ordinary meaning. In the alternative, to the extent the Court determines that a specific	"values in the matrices U, S, or V^H, where $H_{est}=USV^H$"

’450 Patent Claim Term	BNR’s Proposed Construction	Defendants’ Proposed Construction
“coefficients from performing a singular value matrix decomposition (SVD)”	construction is warranted, BNR proposes: “values derived from a singular value decomposition”	

Joint Claim Construction Worksheet, Appendix A at 29–33.

61. In paragraphs 150, Dr. Madisetti states “that SVD must be performed on the wireless signals received by a wireless device from a base station.” Dr. Madisetti’s statement inaccurately interprets the claim language. Claims 1 and 11 recite performing an SVD on “received signals,” while claims 21 and 22 recite performing an SVD on a “plurality of channel estimates.” “Received signals” and “channel estimates” are terms with different meanings. The specification explains this difference using equation [1]:

> A communications medium, such as a radio frequency (RF) channel between a transmitting mobile terminal and a receiving mobile terminal, may be represented by a **transfer system function, H.** The relationship between a time varying **transmitted signal, x(t)**, a time varying **received signal, y(t),** and the systems function may be represented as shown in equation [1]:
>
> $y(t)=H\times x(t)+n(t)$, where equation[1]
>
> n(t) represents noise which may be introduced as the signal travels through the communications medium and the receiver itself.

’450 Patent, 3:53–65. A POSITA would understand that the transfer system function (or just transfer function) “*H*” is how the signal sent by the transmitter “*x(t)*” is *transferred* by the channel. That is to say, “*x(t)*” is modified as “*H*×*x(t)*” after the signal traverses through the channel. As such, a POSITA would understand that a "channel estimate" is represented in equation[1] as a transfer system function, *H*, that describes the properties of the channel (a communications medium). A POSITA would also understand that a "received signal" is the signal received at the antenna of the wireless device and is represented in equation [1] by *y(t)*. A POSITA would know that equation [1] includes *n(t)*, which is the "noise which may be introduced as the signal travels through the communications medium and the receiver itself," and that most, if not all, channels and receivers add such noise.

62. In paragraph 150, Dr. Madisetti states that "[t]he SVD will result in a decomposition of the estimates of the values of H(t)." As I have explained, and as the Defendants' proposed construction of the channel estimate matrices terms indicate, "H_{est} contains estimates of the true values of H(t)." Thus, by substitution, Dr. Madisetti's statement could be rewritten as "[t]he SVD will result in a decomposition of" H_{est}. A POSITA would understand this statement is represented as "equation[2]" consistent with the specification:

$$H_{est}=USV^{H}$$

Id. at 8:52–65. No other SVD equation is disclosed by the specification with respect to the claimed embodiments.

63. In paragraph 151, Dr. Madisetti states that a POSITA would understand the term "coefficients derived from performing a singular value matrix decomposition (SVD)" means "values derived from a singular value decomposition." This construction is not useful because it merely repeats the term to be construed, with the exception of construing the term "coefficients" to mean "values." Both parties agree the term "coefficients" refers to "values" in this context. As I have explained, the "singular value decomposition" results in three matrices. With respect to the claimed embodiments, the specification only discloses SVD

operations using equation [2] with the three matrices represented by the notation U, S, and V^H.

64. In paragraph 152, Dr. Madisetti states that Defendants' construction is wrong because it is limited to the H_{est} matrix. I disagree. As explained above, H_{est} is the only notation used in the specification with respect to the claimed embodiments. The claims do not encompass embodiments identified in the specification using the notation H_{up} and H_{down}. And, as explained above, the claims separately recite limitations for deriving "coefficients" and for transmitting the "coefficients as feedback information," and not transmitting channel estimate matrices (i.e., H_{est}) as feedback.

65. Accordingly, I disagree with Dr. Madisetti's opinion. As stated in my opening declaration, it is my opinion that a POSITA would understand the terms "coefficients derived from performing a singular value matrix decomposition (SVD)" and "coefficients from performing a singular value matrix decomposition (SVD)" to mean "values in the matrices U, S, or V^H, where H_{est}=USV^H."

V. The '862 Patent

A. Person of Ordinary Skill in the Art ("POSITA")

66. Dr. Madisetti states that a POSITA would "have a bachelor's degree in electrical engineering, computer engineering, computer science or similar field, and two to three years of experience in digital communications systems, such as wireless communications systems and networks, or equivalent." Madisetti ¶ 88. I provided a similar opinion. Opening Declaration ¶ 169. Under either definition, however, my opinions in this declaration and in my Opening Declaration remain the same.

B. Construction of the Disputed Terms in the '862 Patent

67. I have reviewed and considered Dr. Madisetti's opinion on the meaning of the disputed terms of the '862 Patent in view of the specification, claims, and

prosecution history, as well as the extrinsic evidence identified by Dr. Madisetti.[3] I disagree with Dr. Madisetti's opinions regarding the proper construction of the disputed terms in the '862 Patent, from the perspective of a POSITA, as explained below. References to the perspective of a POSITA in this section are at the time of filing of the '862 Patent identified in my opening declaration.

a. ***"decompose the estimated transmitter beamforming unitary matrix (V) to produce the transmitter beamforming information"***

'862 Patent Claim Term	BNR's Proposed Construction	Defendants' Proposed Construction
"decompose the estimated transmitter beamforming unitary matrix (V) to produce the transmitter beamforming information"	"factor the estimated transmitter beamforming unitary matrix (V) to produce a reduced number of quantized coefficients"	"factor the estimated transmitter beamforming unitary matrix (V) to produce a reduced set of angles"

Joint Claim Construction Worksheet, Appendix A at 14–15.

[3] Dr. Madisetti identified three publications as extrinsic evidence to support his opinion regarding construction of the "baseband processing module …" terms:

Wireless vs. Wired. How Software Define Radio technology addresses issues related to the use of wireless networks when compared to a wired solution White Paper, Lexycom Technologies, Inc. (May 2005). Madisetti ¶ 106.

Igor S. Simic, Evolution of Mobile Base Station Architectures, Microwave Review at 31 (June 2007). Madisetti ¶ 107.

Rajeesh Kutty, A Simple Baseband Processor for RF Transceivers, Analog Devices. Madisetti ¶ 108.

68. In paragraph 93, Dr. Madisetti confirms that the "Givens rotation operates to reduce the set of coefficients of the estimated transmitter beamforming matrix (V)." As I explained in my opening declaration, the abstract of the '862 Patent states that the Givens Rotation is a QR decomposition operation, which decomposes (factors) a given matrix into the product of two other matrices (Q and R). The specification explains that the Givens Rotation operation reduces the set of angles in the matrix (V):

> The Givens Rotation relies upon the observation that, with the condition of V*V=VV*=I, **some of angles of the Givens Rotation are redundant**. With a decomposed matrix form for the estimated transmitter beamforming matrix (V), **the set of angles fed back to the transmitting wireless device are reduced**.

Id. at 13:65–14:3. Thus, Dr. Madisetti's statement that the Givens Rotation reduces the "set of coefficients" actually refers to reducing "the set of angles."

69. In paragraph 94, Dr. Madisetti errs by construing a "further reduction through quantization" as part of the decomposition operation. According to the plain language of the claim, the "transmitter beamforming information" is produced by "decompos[ing] the estimated transmitter beamforming unitary matrix (V)," not by quantizing coefficients or angles. A POSITA would understand that a Givens Rotation operation does not produce "quantized" data. Instead, a POSITA would understand that quantization refers to a transformation of data into integer values that is not part of a Givens Rotation operation or any other QR decomposition method. The specification discloses a separate quantization operation that transforms angles into a specific number of bits. *Id*. at 15:10–17. In my opinion, a POSITA would understand that Dr. Madisetti is incorrect in construing a decomposition operation to further include a separate quantization operation.

70. Accordingly, I disagree with Dr. Madisetti's opinion. As stated in my opening declaration, it is my opinion that a POSITA would understand the terms "decompose the estimated transmitter beamforming unitary matrix (V) to produce the transmitter beamforming information" to mean "factor the estimated transmitter beamforming unitary matrix (V) to produce a reduced set of angles."

b. "a baseband processing module operable to: receive a preamble sequence carried by the baseband signal; estimate a channel response based upon the preamble sequence; determine an estimated transmitter beamforming unitary matrix (V) based upon the channel response and a receiver beamforming unitary matrix (U); decompose the estimated transmitter beamforming unitary matrix (V) to produce the transmitter beamforming information; and form a baseband signal employed by the plurality of RF components to wirelessly send the transmitter beamforming information to the transmitting wireless device"

'862 Patent Claim Term	BNR's Proposed Construction	Defendants' Proposed Construction
"a baseband processing module operable to: receive a preamble sequence carried by the baseband signal; estimate a channel response based upon the preamble sequence;	Not a 112 ¶ 6 claim element – "baseband processing module" is not a nonce word. Instead, a baseband processing module is itself sufficient structure. A POSA would know this is a baseband processor implemented in ASIC, FGPA, logic	This is a 112 ¶ 6 claim element.

'862 Patent Claim Term	BNR's Proposed Construction	Defendants' Proposed Construction
determine an estimated transmitter beamforming unitary matrix (V) based upon the channel response and a receiver beamforming unitary matrix (U); decompose the estimated transmitter beamforming unitary matrix (V) to produce the transmitter beamforming information; and form a baseband signal employed by the plurality of RF components to wirelessly send the transmitter beamforming information to the transmitting wireless device"	circuits, or the like in RF communication hardware. In the alternative, to the extent the Court determines that this claim is governed by 112 ¶ 6, BNR proposes the following Function and Structure, and disagrees that the term is indefinite for lack of corresponding structure: <u>Function</u>: "receive a preamble sequence carried by the baseband signal; estimate a channel response based upon the preamble sequence; determine an estimated transmitter beamforming unitary matrix (V) based upon the channel response and a receiver beamforming unitary matrix (U); decompose the estimated transmitter beamforming unitary matrix (V) to produce the transmitter beamforming information; and form a baseband signal employed by the plurality of RF	<u>Function</u>: "receive a preamble sequence carried by the baseband signal; estimate a channel response based upon the preamble sequence; determine an estimated transmitter beamforming unitary matrix (V) based upon the channel response and a receiver beamforming unitary matrix (U); decompose the estimated transmitter beamforming unitary matrix (V) to produce the transmitter beamforming information; and form a baseband signal employed by the plurality of RF components to wirelessly send the transmitter beamforming information to

’862 Patent Claim Term	BNR’s Proposed Construction	Defendants’ Proposed Construction
	components to wirelessly send the transmitter beamforming information to the transmitting wireless device” Structure: Corresponding structure for the alleged function exists in at least the following portions of the patent specification, or their equivalents: Figs. 2-5, Col. 5:49–6:12, 6:37–7:20; 7:51–9:30; 9:31–13:35; 13:54–15:67.	the transmitting wireless device” Structure: Indefinite for lack of corresponding structure in the patent specification.

Joint Claim Construction Worksheet, Appendix A at 15–18.

(1) This Term Is A Means-Plus-Function Term

71. Dr. Madisetti states that the “baseband processing module” term of claim 9 is not a means-plus-function term. I disagree.

72. In paragraphs 99 and 101, Dr. Madisetti states that the “baseband processing module” term of claim 9 “refers to a class of structures of baseband processors that may be implemented in whole or in part in ASIC, FGPA, logic circuits, or similar implementation methods in RF communication hardware and software.”

73. In paragraph 101, Dr. Madisetti cites column 8, lines 1–20 as support for his opinion. However, Dr. Madisetti’s analysis of that passage fails to consider that a POSITA would understand its description of “processing devices” that execute operational instructions refers to a general purpose computer requiring specialized

programming to function. Specifically, a POSITA would understand that without specialized programming, a general purpose computer (processing device) could not perform the claimed functions, even if "implemented in whole or in part in ASIC, FGPA [(FPGA)], logic circuits, or similar implementation methods" as Dr. Madisetti states. A POSITA would understand that these specialized functions (i.e., "receive," "estimate," "determine," "decompose," and "form") were not performed by off-the-shelf "processing devices" (general purpose computers) at the time of the filing of the '862 Patent. Because the claim recites functionality performed by a general purpose computer (processing device) without identifying sufficient additional structure, I understand the term must be construed as a means-plus-function term.

74. In paragraph 102, Dr. Madisetti cites column 9, lines 13–30 and states that "wireless communication may be implemented using one or more integrated circuits." This passage states that the "baseband processing module 100" may be combined on the same "integrated circuit" with "memory 52," "memory 65," and "processing module 50." But, combining the general purpose computer (processing device) with other components on an integrated circuit fails to provide sufficient additional structure for performing the specialized functions set forth in claim 9.

75. In paragraph 103, Dr. Madisetti refers to Figure 7 and states the specification "discusses the baseband processing module in the context of specific structure or processing modules." But, Figure 7 identifies functions to be performed (e.g., receive, estimate, convert, decompose, transmit), not the structure for performing these functions.

76. In paragraph 106, Dr. Madisetti references a publication that discloses a "simplified structure" of a Software Designed Radio (SDR). The text below Figure 1 states that the "Base-Band Processing module" of the SDR "retains the **software**, which defines the protocol to be used in the RF channel (RF packets

structure, algorithms of interaction between the nodes in the network, etc.).” It is my opinion that a POSITA would not understand that the “Base-Band Processing module” disclosed by this publication discloses sufficient structure to perform the specialized functions (i.e., “receive,” “estimate,” “determine,” “decompose,” and “form”) set forth in claim 9. For example, a POSITA would understand that the SDR “Base-Band Processing module” includes a general purpose computer that must be programmed with “software” to implement “the protocol to be used in the RF channel.” Like the general purpose computer (processing devices) used to implement the claimed “baseband processing module” disclosed by the ’862 Patent, this publication confirms that the “Base-Band Processing module” of a Software Designed Radio is also implemented using a general purpose computer.

77. In paragraph 107, Dr. Madisetti references a publication disclosing that a “baseband module” has “specific responsibilities in the transmission and receiving of RF signals,” and that “[t]he baseband module processes the encoded signal before transmitting/receiving it from/to the core network through the transmission module.” This publication describes a “baseband module” in functional terms without identifying structure for performing the ‘transmitting/receiving” functions. In my opinion, a POSITA would not understand that the “baseband module” disclosed by this publication discloses sufficient structure to perform the specialized functions (i.e., “receive,” “estimate,” “determine,” “decompose,” and “form”) set forth in claim 9.

78. In paragraph 108, Dr. Madisetti references a publication stating that baseband processing may be implemented using “an ASIC or FPGA” and that “[t]he baseband processor (BBP) allows user data to be processed in the digital domain between an end application and the transceiver device.” Like the ’862 Patent which discloses that an FPGA is used as a general purpose computer “processing device”

"in combination with operational instructions stored in memory" ('862 Patent, 7:56–8:20), a POSITA would understand that this publication similarly fails to disclose sufficient structure implemented using "an ASIC or FPGA" to perform the specialized functions (i.e., "receive," "estimate," "determine," "decompose," and "form") set forth in claim 9.

79. Accordingly, I disagree with Dr. Madisetti's opinion. As stated in my opening declaration, it is my opinion that a POSITA would understand that the claim limitation includes a general purpose computer (e.g., microprocessor). But, that is not sufficient structure to perform the claimed functions. An off-the-shelf general purpose computer is not capable of performing the functions of the claim without special programming. Special programming is necessary for a general purpose computer to perform the "receive," "estimate," "determine," "decompose," and "form" functions. As such, I understand that the "baseband processing module" term must be construed as a means-plus-function term.

(2) This MPF Term Fails To Disclose Algorithms That Define Adequate Structure

80. In paragraph 111, Dr. Madisetti notes that if the term is construed to be a means-plus-function term, the parties agree on the function recited by the term.

81. In paragraphs 112 through 115, Dr. Madisetti contends that the specification establishes that "there is a structure that is **circuitry (including hardware and software)** that controls, based on described inputs, produces certain outputs based on certain types of calculations, and also describes where the information travels next" To support his opinion, Dr. Madisetti refers to "baseband processing module 100" in Figure 3, "baseband receive processing 100-RX" in Figure 4 (presumably intending to identify Figure 5), "beamforming module 144 [that] multiplies a beamforming unitary matrix (U) with baseband signals," and

"flow chart 700 of Figure 7." I disagree that these passages from the specification disclose sufficient structure to make the bounds of the claim understandable to a POSITA.

82. Figure 3 illustrates a box named "baseband processing module" that fails to identify its structure. Figures 4 (100-TX) and 5 (100-RX) identify functional blocks, each named "module," within baseband processing module 100. It is my opinion that a POSITA would understand that baseband processing module 100 includes "hardware and software," as Dr. Madisetti observes. In other words, no specific structure or algorithm is disclosed beyond the general purpose computer (processing device) that the specification explains is used to implement the baseband processing module.

83. Dr. Madisetti describes "beamforming module 144" in purely functional terms: "the beamforming module 144 multiplies a beamforming unitary matrix (U) with baseband signals and is 'functional to produce feedback information for the transmitter as further described with reference to Figure 6.'" Madisetti ¶ 114. For his opinion, Dr. Madisetti relies on the specification at column 12, lines 34–46, but that passage is directed to the function of beamforming module 144 and fails to disclose a specific structure or algorithm.

84. Dr. Madisetti states that "the baseband processing module performs most of the operations of the flow chart 700 of Figure 7." Madisetti ¶ 115. However, Dr. Madisetti provides no basis or reason from which to conclude that "the flow chart 700 of Figure 7" provides a sufficient algorithm. As explained in my opening declaration, Figure 7 fails to disclose an algorithm sufficient to makes the bounds of the claims understandable to a POSITA. Opening Declaration ¶¶ 191–210.

85. Accordingly, I disagree with Dr. Madisetti's opinion. As stated in my opening declaration, it is my opinion that a POSITA would understand that the

baseband processing module term is indefinite for lack of structure to perform the "receive a preamble sequence . . ." function, the "estimate a channel response . . ." function, and the "form a baseband signal . . ." function. Opening Declaration ¶¶ 191–210.

c. "the baseband processing module is operable to: produce the estimated transmitter beamforming unitary matrix (V) in Cartesian coordinates; and convert the estimated transmitter beamforming unitary matrix (V) to polar coordinates"

'862 Patent Claim Term	BNR's Proposed Construction	Defendants' Proposed Construction
"the baseband processing module is operable to: produce the estimated transmitter beamforming unitary matrix (V) in Cartesian coordinates; and convert the estimated transmitter beamforming unitary matrix (V) to polar coordinates"	Not a 112 ¶ 6 claim element – "baseband processing module" is not a nonce word. Instead, a baseband processing module is itself sufficient structure. A POSA would know this is a baseband processor implemented in ASIC, FGPA, logic circuits, or the like in RF communication hardware. In the alternative, to the extent the Court determines that this claim is governed by 112 ¶ 6, BNR proposes the following Function and Structure, and disagrees that the term is indefinite for lack of corresponding structure:	This is a 112 ¶ 6 claim element.

'862 Patent Claim Term	BNR's Proposed Construction	Defendants' Proposed Construction
	Function: "a baseband processing module operable to . . . produce the estimated transmitter beamforming unitary matrix (V) in Cartesian coordinates; and convert the estimated transmitter beamforming unitary matrix (V) to polar coordinates" Structure: Corresponding structure for the alleged function exists in at least the following portions of the patent specification, or their equivalents: Figs. 2-5, Col. 5:49–6:12, 6:37–7:20; 7:51–9:30; 9:31–13:35; 13:54–15:67.	Function: "a baseband processing module operable to . . . produce the estimated transmitter beamforming unitary matrix (V) in Cartesian coordinates; and convert the estimated transmitter beamforming unitary matrix (V) to polar coordinates" Structure: Indefinite for lack of corresponding structure in the patent specification.

Joint Claim Construction Worksheet, Appendix A at 18–21.

(1) This Term Is A Means-Plus-Function Term

86. Dr. Madisetti states that the "baseband processing module" term of claim 10 is not a means-plus-function term. I disagree.

87. In paragraphs 120 and 122, Dr. Madisetti states that the "baseband processing module" term of claim 10 "refers to a class of structures of baseband processors that may be implemented in whole or in part in ASIC, FGPA, logic

circuits, or similar implementation methods in RF communication hardware and software." Dr. Madisetti states that his opinion is based on the same reasons provided in "paragraphs 101–1099" (presumably intending paragraphs 101-109) with respect to claim 9. I disagree for the same reasons explained above with respect to the "baseband processing module" term of claim 9.

88. Accordingly, I disagree with Dr. Madisetti's opinion. As stated in my opening declaration, it is my opinion that a POSITA would understand that the claim limitation includes a general purpose computer (e.g., microprocessor). But, that is not sufficient structure to perform the claimed functions. An off-the-shelf general purpose computer is not capable of performing the functions of the claim without special programming. Special programming is necessary for a general purpose computer to perform the "produce" and "convert" functions. As such, I understand that the "baseband processing module" term must be construed as a means-plus-function term.

(2) This MPF Term Fails To Disclose Algorithms That Define Adequate Structure

89. In paragraph 124, Dr. Madisetti notes that if the term is construed to be a means-plus-function term, the parties agree on the function recited by the term.

90. In paragraph 125, Dr. Madisetti states that the "structure is the baseband processing module of Figure 3 and equivalents thereof," as explained in paragraphs 110–116 with respect to claim 9. I disagree for the same reasons explained above with respect to the "baseband processing module" term of claim 9.

91. In paragraph 126, Dr. Madisetti contends that the specification establishes that "there is a structure that is **circuitry (including hardware and software)** that controls, based on described inputs, produces certain outputs based

on certain types of calculations, and also describes where the information travels next."

92. To support his opinion, Dr. Madisetti refers to "step 706" in Figure 7 and cites the specification at column 13, lines 25 to 35 and lines 54 to 62. I disagree that these passages from the specification disclose sufficient structure to make the bounds of the claim understandable to a POSITA. As explained in my opening declaration, step 706 fails to disclose an algorithm to perform the "convert the estimated transmitter beamforming unitary matrix (V) to polar coordinates" function. Step 706 and the passages cited by Dr. Madisetti merely repeat the recited function without explaining how to perform the "convert" function:

> "Convert estimate of beamforming matrix (V) from Cartesian coordinates to polar coordinates."

'862 Patent, Fig. 7 at step 706.

> According to the embodiment of FIG. 7, the receiving wireless device produces the estimated transmitter beamforming unitary matrix (V) in Cartesian coordinates and then converts the estimated transmitter beamforming unitary matrix (V) to polar coordinates (step 706).

Id. at 13:54–58.

93. Accordingly, I disagree with Dr. Madisetti's opinion. As stated in my opening declaration, it is my opinion that a POSITA would understand that the baseband processing module term is indefinite for lack of structure to perform the "convert the estimated transmitter beamforming unitary matrix (V) to polar coordinates" function. Opening Declaration ¶¶ 216–221.

EXHIBIT E

IN THE UNITED STATES DISTRICT COURT
SOUTHERN DISTRICT OF CALIFORNIA

BELL NORTHERN RESEARCH, LLC, Plaintiff, v. COOLPAD TECHNOLOGIES, INC. AND YULONG COMPUTER COMMUNICATIONS, Defendants.	C.A. No. 3:18-cv-1783-CAB-BLM Judge: Hon. Cathy Ann Bencivengo Magistrate Judge: Hon. Barbara L. Major
BELL NORTHERN RESEARCH, LLC, Plaintiff, v. HUAWEI DEVICE (DONGGUAN) CO., LTD, HUAWEI DEVICE (SHENZHEN) CO., LTD., and HUAWEI DEVICE USA, INC., Defendants.	C.A. No. 3:18-cv-1784-CAB-BLM
BELL NORTHERN RESEARCH, LLC, Plaintiff, v. KYOCERA CORPORATION and KYOCERA INTERNATIONAL INC., Defendants.	C.A. No. 3:18-cv-1785-CAB-BLM

**REBUTTAL DECLARATION OF DR. VIJAY K. MADISETTI, PH.D.
IN SUPPORT OF PLAINTIFF'S CLAIM CONSTRUCTIONS**

TABLE OF CONTENTS

INTRODUCTION

1. On May 2, 2019, I submitted an Opening Declaration on Claim Construction. I hereby incorporate by reference the contents of that declaration in its entirety, including the appendices attached thereto.

2. I have reviewed the declaration of Paul Min, Ph.D., Regarding Claim Construction dated May 1, 2019, concerning United States Patent Nos. 6,941,156 (the '156 Patent); 7,957450 (the '450 Patent); and 8,416,862 (the '862 Patent) ("Min Declaration" or "Min Decl."). Below I provide responses to certain arguments raised by Dr. Min in his declaration.

3. I have reviewed the declaration of Jonathan Wells, Ph.D. dated May 1, 2019, concerning United States Patent Nos. 6,941,156 (the '156 Patent) and 7,990,842 (the '842 Patent) ("Wells Declaration" or "Wells Decl."). Below I provide responses to certain arguments raised by Dr. Wells in his declaration.

U.S. PATENT NO. 6,941,156

4. I understand that Dr. Min's opinions regarding the '156 Patent are at ¶¶ 10–12 and 66–132. Further, I understand that ¶¶ 10–12 are a summary of Dr. Min's opinions, which are further addressed in ¶¶ 66–132. Thus, I disagree with the summary of Dr. Min's opinions in accordance with my disagreements with the specifics of Dr. Min's opinions as discussed further below.

5. I understand that Dr. Wells's opinions regarding the '156 Patent are at ¶¶ 77–108. For the reasons discussed below, I disagree with Dr. Wells's opinions regarding the '156 Patent.

A. Opinions Regarding the Min Declaration

6. In ¶¶ 66–69, Dr. Min quotes portions of the specification of the '156 Patent. I do not dispute that these paragraphs accurately quote the specification.

7. In ¶¶ 70–73, Dr. Min provides his opinion for the definition of a POSITA, which he defines as having a Bachelor's degree in Electrical Engineering, Computer Engineering, Computer Science, or a related field, and at least 2 years of experience in

the field of wireless communication, or a person with equivalent education, work, or experience in this field. I note that my definition of a POSITA includes two to three years of experience in digital communications systems, such as wireless communications systems and networks or the equivalent. Thus, while I disagree with Dr. Min's more narrowed field of experience, however, my opinions also remain the same when I apply Dr. Min's definition of the POSITA as well.

B. Opinions Regarding the Wells Declaration

8. In ¶¶ 77–79, Dr. Wells quotes portions of the specification of the '156 Patent. I do not dispute that these paragraphs accurately quote the specification.

9. In ¶ 80, Dr. Wells provides his opinion for the definition of a POSITA, which he defines as having a bachelor's degree in electrical engineering or a related field, and at least 1–2 years of experience in the field of wireless communication devices, or the equivalent education in the field of wireless communication devices. I note that my definition of a POSITA includes two to three years of experience in digital communications systems, such as wireless communications systems and networks or the equivalent. Thus, while I disagree with Dr. Well's more narrowed field of experience and years of experience, however, my opinions also remain the same when I apply Dr. Wells's definition of a POSITA as well.

C. "simultaneous communication paths from said multimode cell phone"

10. It is my understanding that each side's respective claim construction of the above term from the '156 Patent is as follows:

Plaintiff's Proposed Construction	Defendants' Proposed Construction
Plain and ordinary meaning. In the alternative, to the extent the Court determines that a specific construction is warranted, BNR proposes: "two or more active links at the same time from said multimode cellphone"	"at least two established distinct and different communication links from said multimode cell phone to a far-end communication device, at the same time"

11. For the reasons set forth below, I disagree with Dr. Min's opinion that the term "simultaneous communication paths from said multimode cell phone" should be construed as "at least two established distinct and different communication links from said multimode cell phone to a far-end communication device, at the same time" because it is confusing, imports improper limitations, and has no basis in the specification or intrinsic record.

12. First, I understand that Dr. Min has criticized Plaintiff's proposed construction because the term "active links" is "confusing" and "BNR does not explain the meaning of the term 'active.'" *See* Min Decl. ¶ 86. While Dr. Min considers these two possible conditions to be confusing, they are not—they actually capture the possibilities for an active state of a connection. A connection that is active by maintaining the connected state is no less active when transmission and reception of data begins on that connection. Thus, I disagree that the term "active link" is confusing to a POSITA. On the other hand, I believe that Defendants' use of "established distinct and different" is confusing, as Defendants fail to define what each of those terms mean and has no reference to the specification, intrinsic record, or extrinsic evidence. For example, Dr. Min offers no explanation for why Defendants use the terms "distinct" and "different", seeming synonyms, or whether they are supposed to connote different things and if so, what.

13. I also disagree with Dr. Min's opinions in ¶¶ 88–91 regarding the prosecution history and specifically the arguments made by Applicants in response to a rejection by the Patent Office related to U.S. Patent No. 5,842,122 (Schellinger). Specifically, Dr. Min misreads Applicant's distinguishing of Schellinger regarding the "module to establish simultaneous communication paths from said multimode cell phone" by improperly focusing on the language "a three way call through the cellular telephone system." Dr. Min fails to capture the entire sentence which states that Schellinger operates where "a call in process is handed off by producing a THREE WAY CALL <u>through the cellular telephone system</u> (i.e., NOT through the cell phone

itself)" and in doing so, fails to connect the first sentence which states that in Schellinger "automatic forwarding systems of a central office are implemented to allow handoff of a call." Read together, Schellinger describes a multimode cellular phone that requires a cellular telephone system or central office to establish the second communication link on the multimode cellular phone. The Applicant contrasted Schellinger with the invention by noting that the multimode cellular phone of the invention is able to establish the second communication link without having a second call forwarded to it (i.e. relying on an external source to establish the second link with the multimode cellular phone). Dr. Min improperly applies this requirement to the far end device, though the specification only spoke with regard to the multimode cellphone that represents the near-end device. Thus, Dr. Min misinterprets the prosecution history, which in fact supports BNR's claim construction position.

14. I disagree with Dr. Min's opinions, in ¶¶ 79–85, related to the specification of the '156 Patent. Specifically, I disagree with Dr. Min's incorrect interpretation of Figure 1, where he improperly labels the "initial telephone call" and the "handed over telephone call" as the "distinct and different communication links" to a "far end communication device." *See* Min Decl. ¶ 80. This interpretation is plainly inconsistent with the specification, for at least two reasons. First, the portions of Figure 1 that Dr. Min identifies as the relevant communication paths ("initial telephone call" and "handed over telephone call") do not even extend from the multimode cellular telephone, but instead only begin at elements 120 and 110. This interpretation is inconsistent with the claim language itself, which requires the multimode cellular phone to establish both links. Second, Figure 1 plainly identifies each link as "1st" and "2nd" and shows an RF connection from the multimode cellular phone to 120 and another connection to the piconet base station 110. Then, each of cellular network 120 and base unit 110 have a clear connection to the PSTN 130. Within PSTN 130, one embodiment of the handover, a Type 2 Call Waiting Service

140, is identified. And finally, there is a single link from the PSTN 130 to the far-end communication device 150.

15. Thus, it is my opinion that Defendants' construction is incorrect because it improperly requires two links to be active at the far-end communication device, despite clear evidence to the contrary from the specification. Further, Defendants' use of ambiguous terms like "distinct and different" have no definition or reference in the specification. Finally, Dr. Min incorrectly interprets the prosecution history, which actually supports BNR's construction and contradicts Defendants' proposed construction.

D. "cell phone functionality"

16. It is my understanding that the following parties have the following positions on the above term from the '156 Patent:

Plaintiff's Proposed Construction	Kyocera's Proposed Construction	Huawei & Coolpad's Proposed Construction
Not a 112 ¶ 6 claim element – "cell phone functionality" is not a nonce word. Instead, cell phone functionality is itself sufficient structure. A POSA would know that this is a cellular RF communication functionality well known in the art.	This is a 112 ¶ 6 claim element. <u>Function</u>: "cell phone" <u>Structure</u>: Indefinite for lack of corresponding structure in the patent specification.	This is a 112 ¶ 6 claim element. <u>Function</u>: "cell phone" <u>Structure</u>: Indefinite for lack of corresponding structure in the patent specification. Alternatively, to the extent that the Court requires an identification of structure, the cell phone 100a and corresponding antenna depicted in Fig. 1 are insufficient structure to perform the claimed function.

17. For the reasons set forth below, I disagree with Dr. Min's opinion that the term "cell phone functionality" should be governed by 112 ¶ 6 because a POSITA

would know that this is a cellular RF communication functionality that is well known in the art.

18. First, I disagree with Dr. Min's interpretation of "cell phone functionality" to be related to the multimode cell phone 100, instead of the cell phone functionality 100a that is described by the '156 Patent, in Figure 1 and the specification, which identifies "the cell phone functionality 100a." *See* '156 Patent at Col. 3:55–58. Dr. Min incorrectly interprets cell phone functionality to include "the ability and convenience of storing all phone book data, calling history, and user preference," which actually relates to the multimode cell phone 100 and not the cell phone functionality 100a.

19. Second, Dr. Min admits that a POSITA would understand that cell phone functionality requires "radio communication equipment (e.g. amplifier, transmitter, receiver, etc.) operating in conjunction with [a processor] . . . to perform wireless communications, typically in compliance with telecommunication industry standards (e.g., 3GPP/ETSI, etc.). *See* Min Decl. ¶ 100. Thus, Dr. Min appears to acknowledge that a POSITA would understand that cell phone functionality is a cellular RF communication functionality and that a POSITA would understand that cell phone functionality by itself refers to sufficient structure.

20. Dr. Min primarily appears to disagree with BNR's construction because "the claimed 'multimode cell phone' cannot be limited to 'cellular RF communication functionality' because it includes functionality to operate as a cordless telephone or walkie-talkie, and because it includes functionality to store phone book data, calling history, and user preferences." *See* Min Decl. ¶ 101. Dr. Min is improperly construing "multimode cell phone" and not the term "cell phone functionality" which is a part of (but not the entirety of) the claimed multimode cell phone, as discussed above. Indeed, the specification makes clear that Dr. Min's claimed functions are separate (e.g. 100b for RF functionality, 100c for walkie-talkie functionality) from the cell phone functionality.

21. Finally, Dr. Min states that BNR's proposed construction fails to recognize that a POSITA would understand that the claimed multimode cell phone includes a general purpose computer programmed to perform wireless communications. It is my opinion that this is incorrect because (1) Dr. Min again improperly focuses on the multimode cell phone instead of the cell phone functionality and (2) Dr. Min admits in his declaration that a POSITA would understand that cell phone functionality requires radio communication equipment and a specific processor programmed in accordance with industry standards.

22. Therefore it is my opinion that the term "cell phone functionality" is not governed by 112 ¶ 6, but that a POSITA would know that this is a cellular RF communication functionality that is well known in the art.

E. "RF functionality"

23. It is my understanding that the following parties have the following positions on the above term from the '156 Patent:

Plaintiff's Proposed Construction	Kyocera's Proposed Construction	Huawei & Coolpad's Proposed Construction
Not a 112 ¶ 6 claim element – "RF communication functionality" RF communication functionality is itself sufficient structure. A POSA would know that this is a structure for RF communications through a genus of RF communication types well known in the art.	This is a 112 ¶ 6 claim element. <u>Function</u>: "RF communication" <u>Structure</u>: Indefinite for lack of corresponding structure in the patent specification.	This is a 112 ¶ 6 claim element. <u>Function</u>: "RF communication" <u>Structure</u>: Indefinite for lack of corresponding structure in the patent specification. Alternatively, to the extent that the Court requires an identification of structure, any of the cordless phone 100b with its corresponding antenna and the walkie-talkie 100c with its corresponding antenna, are

Plaintiff's Proposed Construction	Kyocera's Proposed Construction	Huawei & Coolpad's Proposed Construction
		insufficient structure to perform the claimed function.

24. For the reasons set forth below, I disagree with Dr. Min's opinion that the term "RF communication functionality" should be governed by 112 ¶ 6 because a POSITA would know that RF communication functionality is itself structure and further that a POSITA would know that RF communication functionality is a structure for RF communications through a genus of RF communication types well known in the art.

25. Dr. Min's opinion is based on his belief that the "RF communication functionality" is used solely in the context of the claimed multimode cell phone and therefore must include a general purpose computer. *See* Min Decl. ¶¶ 106–109. I disagree. First, I disagree that it is proper to incorporate RF communication into the claimed multimode cell phone in the manner in which Dr. Min is doing. The RF functionality is a separate element of the claimed device and has its own structure (*see, e.g.*, elements 100a, 100b, each of which have their own antennas and are described distinctly in the specification of the '156 Patent, *see, e.g.*, Col. 3:64–4:6).

26. I also disagree that the RF communication functionality would include a general purpose computer. Instead, a POSITA would understand that an RF communication functionality would utilize hardware and software specifically programed and implemented for the relevant RF type and that such hardware and software was, at the time of the invention, routinely purchased or implemented as distinct, specialized hardware and software from a manufacturer and installed into a cell phone. The RF communication types encompassed by this structure are well known in the art and governed by relevant industry standards.

27. Thus, I disagree with Dr. Min's opinion that this term should be construed as means-plus-function. It should not.

F. "a module to establish simultaneous communication paths from said multimode cell phone using both said cell phone functionality and said RF communication functionality"

28. It is my understanding that the following parties have the following positions on the above term from the '156 Patent:

Plaintiff's Proposed Construction	Kyocera's Proposed Construction	Huawei & Coolpad's Proposed Construction
Not a 112 ¶ 6 claim element – In the alternative, to the extent the Court determines that this claim is governed by 112 ¶ 6, BNR proposes the following Function and Structure, and disagrees that the term is indefinite for lack of corresponding structure: Function: establish simultaneous communication paths from said multimode cell phone using both said cell phone functionality and said RF communication functionality Structure: Corresponding structure for the alleged function exists in at least the following portions of the patent specification, or their equivalents: Figs. 1, 3, Col. 3:48–4:49; 4:54–5:62; 6:3–55; 6:60–8:5	This is a 112 ¶ 6 claim element. Function: "establish simultaneous communication paths from said multimode cell phone using both said cell phone functionality and said RF communication functionality" Structure: Indefinite for lack of corresponding structure in the patent specification.	This is a 112 ¶ 6 claim element. Function: "establish simultaneous communication paths from said multimode cell phone using both said cell phone functionality and said RF communication functionality" Structure: Fig. 1 (element 101); Fig. 2 steps 202-208; Fig. 4 steps 402-408; 4:50-67; 7:1-16.

29. I note that the Defendants are unable to agree on whether (and what) structure is disclosed in the patent with respect to this claim term, and, accordingly, have proffered a declaration from two different experts on this claim term. However, I disagree with both Dr. Wells and Dr. Min.

30. For the reasons set forth below, I disagree with Dr. Wells's opinion that this term is subject to Section 112(6) and/or that it "does not have a well-known structural meaning in the field." *See* Wells Decl. ¶ 83. Likewise, I disagree with Dr. Min's opinion that the term is subject to § 112(6) and that a POSITA would understand the structure includes a general purpose computer. *See* Min Decl. ¶¶ 112–116.

31. I disagree with Dr. Wells's and Dr. Min's opinions that the written description and the prosecution history fails to impart any structural significance to this term. As stated in my opening report, it is my opinion that a POSITA, viewing the term in light of the specification, would understand that it refers to a known class of structures within multimode cell phones that negotiate and control each of the modes of communication. *See* Madisetti Opening Decl. ¶¶ 56-60.

32. Further, as stated in my opening declaration, I disagree with Dr. Min that if the term is subject to § 112(6), that there is insufficient structure. I also note that Dr. Wells disagrees with Dr. Min's opinion that the specification lacks sufficient structure. *See* Wells Decl. ¶¶ 88–96. That said, it is my opinion that Dr. Wells does not identify the correct structure. The parties agree that, should the Court determine the term to be governed by § 112(6), that the relevant function is "to establish simultaneous communication paths." Dr. Wells begins his analysis with the flawed assumption that a "POSITA would recognize that the function…is implemented by a computer/processor" and that therefore an algorithm must be identified. But a POSITA, well-versed in the field of wireless communication technology, would understand that each mode of communication (e.g., cell phone, wireless, etc.) is controlled by hardware and software components in a multimode cell phone interacting with transceivers. This would have been basic knowledge at the time of the invention, and it goes beyond mere computer processing technology.

33. Dr. Min opines that Steps 202, 204, 206, and 208 fail to recite an algorithm to a POSITA. *See* Min Decl. ¶¶ 118–121. I note that these steps are the

exact steps that Dr. Wells identifies as the corresponding structure that is sufficient to a POSITA, and therefore that Dr. Wells was able to determine that a POSITA would understand the algorithm that Dr. Min was unable to identify. *See* Wells Decl. ¶¶ 92–96.

34. For the reasons stated in my opening declaration, however, I disagree with Dr. Wells's conclusion that the corresponding structures for this term "are the algorithm provided by steps 202-208 in FIG. 2 and the algorithm provided by steps 402-408 in FIG. 4…" First, FIG. 2 and 4 merely present two embodiments of the claimed invention that vary by *communication mode.* In other words, neither of those figures have any bearing on the functionality and structure disclosed for this term in the specification, because they represent examples of types of *communication paths* – not the module to establish them.

35. Second, Dr. Wells fails to address FIG. 1 and the portions of the specification that describe the structures with which "more than one mode of the multimode cell phone 100 may operate simultaneously…" '156 Patent at Col. 3:64–4:1. As I explained in my opening declaration, the specification, in conjunction with FIG. 1, discloses to one of skill in the art the various components and tools relevant to establishing the communication paths. *See* Madisetti Opening Decl. ¶¶ 61-68.

G. "an automatic switch over module, in communication with both said cell phone functionality and said RF communication functionality, operable to switch a communication path established on one of said cell phone functionality and said RF communication functionality, with another communication path later established on the other of said cell phone functionality and said RF communication functionality"

36. It is my understanding that the following parties have the following positions on the above term from the '156 Patent: