8078660

THE UNITED STATES OF AMERICA

TO ALL TO WHOM THESE PRESENTS SHALL COME:

UNITED STATES DEPARTMENT OF COMMERCE

United States Patent and Trademark Office

January 22, 2021

THIS IS TO CERTIFY THAT ANNEXED IS A TRUE COPY FROM THE RECORDS OF THIS OFFICE OF THE FILE WRAPPER AND CONTENTS OF:

APPLICATION NUMBER: ***15/105,648***
FILING DATE: ***June 17, 2016***
PATENT NUMBER: ***10193600***
ISSUE DATE: ***January 29, 2019***

UNITED STATES PATENT AND TRADEMARK OFFICE · DEPARTMENT OF COMMERCE

Certified by

Under Secretary of Commerce
for Intellectual Property
and Director of the United States
Patent and Trademark Office

TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A SUBMISSION UNDER 35 U.S.C. 371		Attorney Docket No. 4015-9595 / P45698-US2 U.S. Application No. (if known, see 37 CFR 1.5)
International Application No. PCT/SE2016/050009	International Filing Date 2016-01-11	Priority Date Claimed 2015-01-14
Title of Invention Codebook Subset Restriction Signaling		
First Named Inventor Faxér, Sebastian		

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information.

1. ☑ This is an express request to begin national examination procedures (35 U.S.C. 371(f)). NOTE: The express request under 35 U.S.C. 371(f) will not be effective unless the requirements under 35 U.S.C. 371(c)(1), (2), and (4) for payment of the basic national fee, copy of the International Application and English translation thereof (if required), and the oath or declaration of the inventor(s) have been received.
2. ☑ A copy of the International Application (35 U.S.C. 371(c)(2)) is attached hereto (not required if the International Application was previously communicated by the International Bureau or was filed in the United States Receiving Office (RO/US)).
3. An English language translation of the International Application (35 U.S.C. 371(c)(2))
   a. ☑ is attached hereto.
   b. ☐ has been previously submitted under 35 U.S.C. 154(d)(4).
4. An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4))
   a. ☑ is attached.
   b. ☐ was previously filed in the international phase under PCT Rule 4.17(iv).

Items 5 to 8 below concern amendments made in the international phase.

PCT Article 19 and 34 amendments

5. ☐ Amendments to the claims under PCT Article 19 are attached (not required if communicated by the International Bureau) (35 U.S.C. 371(c)(3)).
6. ☐ English translation of the PCT Article 19 amendment is attached (35 U.S.C. 371(c)(3)).
7. ☐ English translation of annexes (Article 19 and/or 34 amendments only) of the International Preliminary Examination Report is attached (35 U.S.C. 371(c)(5)).

Cancellation of amendments made in the international phase

8a. ☐ Do not enter the amendment made in the international phase under PCT Article 19.

8b. ☐ Do not enter the amendment made in the international phase under PCT Article 34.

NOTE: A proper amendment made in English under Article 19 or 34 will be entered in the U.S. national phase application absent a clear instruction from applicant not to enter the amendment(s).

The following items 9 to 17 concern a document(s) or information included.

9. ☑ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
10. ☑ A preliminary amendment.
11. ☑ An Application Data Sheet under 37 CFR 1.76.
12. ☐ A substitute specification. NOTE: A substitute specification cannot include claims. See 37 CFR 1.125(b).
13. ☑ A power of attorney and/or change of address letter.
14. ☐ A computer-readable form of the sequence listing in accordance with PCT Rule 13*ter*.3 and 37 CFR 1.821-1.825.
15. ☑ Assignment papers *(cover sheet and document(s))*. Name of Assignee: Telefonaktiebolaget LM Ericsson (publ)
16. ☑ 37 CFR 3.73(c) Statement *(when there is an Assignee)*.

U.S. APPLN. No. (if known – see 37 CFR 1.5)	INTERNATIONAL APPLICATION No.	ATTORNEY DOCKET No.
	PCT/SE2016/050009	4015-9595 / P45698-US2

17. ☑ Other items or information:

PCT Request
PCT Receipt

The following fees have been submitted.	CALCULATIONS	PTO USE ONLY
18. ☑ Basic national fee (37 CFR 1.492(a)) $280	$ 280	
19. ☑ Examination fee (37 CFR 1.492(c)) If the written opinion prepared by ISA/US or the international preliminary examination report prepared by IPEA/US indicates all claims satisfy provisions of PCT Article 33(1)-(4) .... $0 All other situations $720	$ 720	
20. ☑ Search fee (37 CFR 1.492(b)) If the written opinion prepared by ISA/US or the international preliminary examination report prepared by IPEA/US indicates all claims satisfy provisions of PCT Article 33(1)-(4) .... $0 Search fee (37 CFR 1.445(a)(2)) has been paid on the international application to the USPTO as an International Searching Authority .... $120 International Search Report prepared by an ISA other than the US and provided to the Office or previously communicated to the US by the IB .... $480 All other situations $600	$ 600	
TOTAL OF 18, 19, and 20 =	$ 1600	
☐ Additional fee for specification and drawings filed in paper over 100 sheets (excluding sequence listing in compliance with 37 CFR 1.821(c) or (e) in an electronic medium or computer program listing in an electronic medium) (37 CFR 1.492(j)). Fee for each additional 50 sheets of paper or fraction thereof $400		

Total Sheets	Extra Sheets	Number of each addition 50 or fraction thereof (round **up** to a whole number)	RATE		
- 100 =	/ 50 =		x $400	$	

Surcharge of **$140.00** for furnishing any of the search fee, examination fee, or the oath or declaration after the date of commencement of the national stage (37 CFR 1.492(h)).	$	

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total claims	- 20 =	12	x $80	$ 960	
Independent claims	- 3 =	1	x $420	$ 420	
MULTIPLE DEPENDENT CLAIM(S) (if applicable)			+ $780	$	
Processing fee of **$140.00** for furnishing the English translation later than 30 months from the earliest claimed priority date (37 CFR 1.492(i)). +				$	
TOTAL OF ABOVE CALCULATIONS =				$ 2980	
☐ **Applicant asserts small entity status.** See 37 CFR 1.27. Fees above are reduced by ½.					
☐ **Applicant certifies micro entity status.** See 37 CFR 1.29. Fees above are reduced by ¾. Applicant must attach form PTO/SB/15A or B or equivalent.					
TOTAL NATIONAL FEE =				$ 2980	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). **$40.00** per property. +				$	
TOTAL FEES ENCLOSED =				$ 2980	
				Amount to be refunded:	$
				Amount to be charged:	$

a. ☐ A check in the amount of $__________ to cover the above fees is enclosed.

b. ☐ Please charge my Deposit Account No. __________ in the amount of $__________ to cover the above fees.

c. ☑ The Director is hereby authorized to charge additional fees which may be required, or credit any overpayment, to Deposit Account No. 181167 as follows:

i. ☐ any required fee.

ii. ☑ any required fee except for excess claims fees required under 37 CFR 1.492(d) and (e) and multiple dependent claim fee required under 37 CFR 1.492(f).

d. ☐ Fees are to be charged to a credit card. **WARNING:** Information on this form may become public. Credit card information should not be included on this form. Provide credit card information and authorization on PTO-2038. The PTO-2038 should only be mailed or faxed to the USPTO. However, when paying the basic national fee, the PTO-2038 may NOT be faxed to the USPTO.

ADVISORY: If filing by EFS-Web, do **NOT** attach the PTO-2038 form as a PDF along with your EFS-Web submission. Please be advised that this is **not** recommended and by doing so your **credit card information may be displayed via PAIR**. To protect your information, it is recommended to pay fees online by using the electronic payment method.

NOTE: Where an appropriate time limit under 37 CFR 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the International Application to pending status.

Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File)Transition Applications

☐ This application (1) claims priority to or the benefit of an application filed before March 16, 2013, and (2) also contains, or contained at any time, a claim to a claimed invention that has an effective filing date on or after March 16, 2013.

NOTE 1: By providing this statement under 37 CFR 1.55 or 1.78, **this application, with a filing date on or after March 16, 2013, will be examined under the first inventor to file provisions of the AIA.**

NOTE 2: A U.S. national stage application may not claim priority to the international application of which it is the national phase. The filing date of a U.S. national stage application is the international filing date. See 35 U.S.C. 363.

Correspondence Address

☑ The address associated with Customer Number: 24112 **OR** ☐ Correspondence address below

Name					
Address					
City		State		Zip Code	
Country			Telephone		
Email					

Signature	/ Justin J. Leonard /	Date	2016-06-17
Name (Print/Type)	Justin J. Leonard	Registration No. (Attorney/Agent)	60986

Privacy Act Statement

The **Privacy Act of 1974 (P.L. 93-579)** requires that you be given certain information in connection with your submission of the attached form related to a patent application or patent. Accordingly, pursuant to the requirements of the Act, please be advised that: (1) the general authority for the collection of this information is 35 U.S.C. 2(b)(2); (2) furnishing of the information solicited is voluntary; and (3) the principal purpose for which the information is used by the U.S. Patent and Trademark Office is to process and/or examine your submission related to a patent application or patent. If you do not furnish the requested information, the U.S. Patent and Trademark Office may not be able to process and/or examine your submission, which may result in termination of proceedings or abandonment of the application or expiration of the patent.

The information provided by you in this form will be subject to the following routine uses:

1. The information on this form will be treated confidentially to the extent allowed under the Freedom of Information Act (5 U.S.C. 552) and the Privacy Act (5 U.S.C 552a). Records from this system of records may be disclosed to the Department of Justice to determine whether disclosure of these records is required by the Freedom of Information Act.
2. A record from this system of records may be disclosed, as a routine use, in the course of presenting evidence to a court, magistrate, or administrative tribunal, including disclosures to opposing counsel in the course of settlement negotiations.
3. A record in this system of records may be disclosed, as a routine use, to a Member of Congress submitting a request involving an individual, to whom the record pertains, when the individual has requested assistance from the Member with respect to the subject matter of the record.
4. A record in this system of records may be disclosed, as a routine use, to a contractor of the Agency having need for the information in order to perform a contract. Recipients of information shall be required to comply with the requirements of the Privacy Act of 1974, as amended, pursuant to 5 U.S.C. 552a(m).
5. A record related to an International Application filed under the Patent Cooperation Treaty in this system of records may be disclosed, as a routine use, to the International Bureau of the World Intellectual Property Organization, pursuant to the Patent Cooperation Treaty.
6. A record in this system of records may be disclosed, as a routine use, to another federal agency for purposes of National Security review (35 U.S.C. 181) and for review pursuant to the Atomic Energy Act (42 U.S.C. 218(c)).
7. A record from this system of records may be disclosed, as a routine use, to the Administrator, General Services, or his/her designee, during an inspection of records conducted by GSA as part of that agency's responsibility to recommend improvements in records management practices and programs, under authority of 44 U.S.C. 2904 and 2906. Such disclosure shall be made in accordance with the GSA regulations governing inspection of records for this purpose, and any other relevant (*i.e.*, GSA or Commerce) directive. Such disclosure shall not be used to make determinations about individuals.
8. A record from this system of records may be disclosed, as a routine use, to the public after either publication of the application pursuant to 35 U.S.C. 122(b) or issuance of a patent pursuant to 35 U.S.C. 151. Further, a record may be disclosed, subject to the limitations of 37 CFR 1.14, as a routine use, to the public if the record was filed in an application which became abandoned or in which the proceedings were terminated and which application is referenced by either a published application, an application open to public inspection or an issued patent.
9. A record from this system of records may be disclosed, as a routine use, to a Federal, State, or local law enforcement agency, if the USPTO becomes aware of a violation or potential violation of law or regulation.

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	4015-9595 / P45698-US2
	Application Number	

Title of Invention	Codebook Subset Restriction Signaling

The application data sheet is part of the provisional or nonprovisional application for which it is being submitted. The following form contains the bibliographic data arranged in a format specified by the United States Patent and Trademark Office as outlined in 37 CFR 1.76.
This document may be completed electronically and submitted to the Office in electronic format using the Electronic Filing System (EFS) or the document may be printed and included in a paper filed application.

Secrecy Order 37 CFR 5.2:

☐ Portions or all of the application associated with this Application Data Sheet may fall under a Secrecy Order pursuant to 37 CFR 5.2 (Paper filers only. Applications that fall under Secrecy Order may not be filed electronically.)

Inventor Information:

Inventor 1 Remove
Legal Name

Prefix	Given Name	Middle Name	Family Name	Suffix
	Sebastian		Faxér	

Residence Information (Select One) ○ US Residency ● Non US Residency ○ Active US Military Service

City	Järfälla	Country of Residence i	SE

Mailing Address of Inventor:

Address 1	Barkarbyvägen 53 D		
Address 2			
City	Järfälla	State/Province	
Postal Code	SE-17744	Country i	SE

Inventor 2 Remove
Legal Name

Prefix	Given Name	Middle Name	Family Name	Suffix
	Mattias		Frenne	

Residence Information (Select One) ○ US Residency ● Non US Residency ○ Active US Military Service

City	Uppsala	Country of Residence i	SE

Mailing Address of Inventor:

Address 1	Arkeologvägen 20		
Address 2			
City	Uppsala	State/Province	
Postal Code	SE-75443	Country i	SE

Inventor 3 Remove
Legal Name

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	4015-9595 / P45698-US2
	Application Number	

Title of Invention	Codebook Subset Restriction Signaling

Prefix	Given Name	Middle Name	Family Name	Suffix
	Simon		Järmyr	

Residence Information (Select One) US Residency (●) Non US Residency Active US Military Service

City	Skarpnäck	Country of Residence	SE

Mailing Address of Inventor:

Address 1	Luftfartsgatan 8		
Address 2			
City	Skarpnäck	**State/Province**	
Postal Code	SE-12834	**Country**	SE

Inventor 4 Remove
Legal Name

Prefix	Given Name	Middle Name	Family Name	Suffix
	George		Jöngren	

Residence Information (Select One) US Residency (●) Non US Residency Active US Military Service

City	Sundbyberg	Country of Residence	SE

Mailing Address of Inventor:

Address 1	Kronogårdsvägen 44		
Address 2			
City	Sundbyberg	**State/Province**	
Postal Code	SE-17462	**Country**	SE

Inventor 5 Remove
Legal Name

Prefix	Given Name	Middle Name	Family Name	Suffix
	Niklas		Wernersson	

Residence Information (Select One) US Residency (●) Non US Residency Active US Military Service

City	Solna	Country of Residence	SE

Mailing Address of Inventor:

Address 1	Tunvägen 14		
Address 2			
City	Solna	**State/Province**	
Postal Code	SE-17068	**Country**	SE

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	4015-9595 / P45698-US2
	Application Number	

Title of Invention	Codebook Subset Restriction Signaling

All Inventors Must Be Listed - Additional Inventor Information blocks may be generated within this form by selecting the **Add** button. Add

Correspondence Information:

Enter either Customer Number or complete the Correspondence Information section below. For further information see 37 CFR 1.33(a).

☐ **An Address is being provided for the correspondence Information of this application.**

Customer Number	24112	
Email Address		Add Email Remove Email

Application Information:

Title of the Invention	Codebook Subset Restriction Signaling		
Attorney Docket Number	4015-9595 / P45698-US2	**Small Entity Status Claimed** ☐	
Application Type	Nonprovisional		
Subject Matter	Utility		
Total Number of Drawing Sheets (if any)	14	**Suggested Figure for Publication (if any)**	

Filing By Reference:

Only complete this section when filing an application by reference under 35 U.S.C. 111(c) and 37 CFR 1.57(a). Do not complete this section if application papers including a specification and any drawings are being filed. Any domestic benefit or foreign priority information must be provided in the appropriate section(s) below (i.e., "Domestic Benefit/National Stage Information" and "Foreign Priority Information").

For the purposes of a filing date under 37 CFR 1.53(b), the description and any drawings of the present application are replaced by this reference to the previously filed application, subject to conditions and requirements of 37 CFR 1.57(a).

Application number of the previously filed application	Filing date (YYYY-MM-DD)	Intellectual Property Authority or Country

Publication Information:

☐ Request Early Publication (Fee required at time of Request 37 CFR 1.219)

☐ **Request Not to Publish.** I hereby request that the attached application not be published under 35 U.S.C. 122(b) and certify that the invention disclosed in the attached application **has not and will not** be the subject of an application filed in another country, or under a multilateral international agreement, that requires publication at eighteen months after filing.

Representative Information:

Representative information should be provided for all practitioners having a power of attorney in the application. Providing this information in the Application Data Sheet does not constitute a power of attorney in the application (see 37 CFR 1.32).
Either enter Customer Number or complete the Representative Name section below. If both sections are completed the customer Number will be used for the Representative Information during processing.

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	4015-9595 / P45698-US2
	Application Number	
Title of Invention	Codebook Subset Restriction Signaling	

Please Select One:	● Customer Number	US Patent Practitioner	◯ Limited Recognition (37 CFR 11.9)
Customer Number	24112		

Domestic Benefit/National Stage Information:

This section allows for the applicant to either claim benefit under 35 U.S.C. 119(e), 120, 121, 365(c), or 386(c) or indicate National Stage entry from a PCT application. Providing benefit claim information in the Application Data Sheet constitutes the specific reference required by 35 U.S.C. 119(e) or 120, and 37 CFR 1.78.
When referring to the current application, please leave the "Application Number" field blank.

Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing or 371(c) Date (YYYY-MM-DD)
	a 371 of international	PCT/SE2016/050009	2016-01-11
Prior Application Status	Expired		Remove
Application Number	Continuity Type	Prior Application Number	Filing or 371(c) Date (YYYY-MM-DD)
PCT/SE2016/050009	Claims benefit of provisional	62/103101	2015-01-14

Additional Domestic Benefit/National Stage Data may be generated within this form by selecting the **Add** button. Add

Foreign Priority Information:

This section allows for the applicant to claim priority to a foreign application. Providing this information in the application data sheet constitutes the claim for priority as required by 35 U.S.C. 119(b) and 37 CFR 1.55. When priority is claimed to a foreign application that is eligible for retrieval under the priority document exchange program (PDX)[i] the information will be used by the Office to automatically attempt retrieval pursuant to 37 CFR 1.55(i)(1) and (2). Under the PDX program, applicant bears the ultimate responsibility for ensuring that a copy of the foreign application is received by the Office from the participating foreign intellectual property office, or a certified copy of the foreign priority application is filed, within the time period specified in 37 CFR 1.55(g)(1).

Application Number	Country[i]	Filing Date (YYYY-MM-DD)	Remove Access Code[i] (if applicable)

Additional Foreign Priority Data may be generated within this form by selecting the **Add** button. Add

Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	4015-9595 / P45698-US2
	Application Number	

Title of Invention	Codebook Subset Restriction Signaling

☐ This application (1) claims priority to or the benefit of an application filed before March 16, 2013 and (2) also contains, or contained at any time, a claim to a claimed invention that has an effective filing date on or after March 16, 2013.
NOTE: By providing this statement under 37 CFR 1.55 or 1.78, this application, with a filing date on or after March 16, 2013, will be examined under the first inventor to file provisions of the AIA.

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	4015-9595 / P45698-US2
	Application Number	

Title of Invention	Codebook Subset Restriction Signaling

Authorization or Opt-Out of Authorization to Permit Access:

When this Application Data Sheet is properly signed and filed with the application, applicant has provided written authority to permit a participating foreign intellectual property (IP) office access to the instant application-as-filed (see paragraph A in subsection 1 below) and the European Patent Office (EPO) access to any search results from the instant application (see paragraph B in subsection 1 below).

Should applicant choose not to provide an authorization identified in subsection 1 below, applicant **must opt-out** of the authorization by checking the corresponding box A or B or both in subsection 2 below.

NOTE: This section of the Application Data Sheet is **ONLY** reviewed and processed with the **INITIAL** filing of an application. After the initial filing of an application, an Application Data Sheet cannot be used to provide or rescind authorization for access by a foreign IP office(s). Instead, Form PTO/SB/39 or PTO/SB/69 must be used as appropriate.

1. Authorization to Permit Access by a Foreign Intellectual Property Office(s)

A. Priority Document Exchange (PDX) - Unless box A in subsection 2 (opt-out of authorization) is checked, the undersigned hereby **grants the USPTO authority** to provide the European Patent Office (EPO), the Japan Patent Office (JPO), the Korean Intellectual Property Office (KIPO), the State Intellectual Property Office of the People's Republic of China (SIPO), the World Intellectual Property Organization (WIPO), and any other foreign intellectual property office participating with the USPTO in a bilateral or multilateral priority document exchange agreement in which a foreign application claiming priority to the instant patent application is filed, access to: (1) the instant patent application-as-filed and its related bibliographic data, (2) any foreign or domestic application to which priority or benefit is claimed by the instant application and its related bibliographic data, and (3) the date of filing of this Authorization. See 37 CFR 1.14(h)(1).

B. Search Results from U.S. Application to EPO - Unless box B in subsection 2 (opt-out of authorization) is checked, the undersigned hereby **grants the USPTO authority** to provide the EPO access to the bibliographic data and search results from the instant patent application when a European patent application claiming priority to the instant patent application is filed. See 37 CFR 1.14(h)(2).

The applicant is reminded that the EPO's Rule 141(1) EPC (European Patent Convention) requires applicants to submit a copy of search results from the instant application without delay in a European patent application that claims priority to the instant application.

2. Opt-Out of Authorizations to Permit Access by a Foreign Intellectual Property Office(s)

☐ A. Applicant **DOES NOT** authorize the USPTO to permit a participating foreign IP office access to the instant application-as-filed. If this box is checked, the USPTO will not be providing a participating foreign IP office with any documents and information identified in subsection 1A above.

☐ B. Applicant **DOES NOT** authorize the USPTO to transmit to the EPO any search results from the instant patent application. If this box is checked, the USPTO will not be providing the EPO with search results from the instant application.

NOTE: Once the application has published or is otherwise publicly available, the USPTO may provide access to the application in accordance with 37 CFR 1.14.

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	4015-9595 / P45698-US2
	Application Number	
Title of Invention	Codebook Subset Restriction Signaling	

Applicant Information:

Providing assignment information in this section does not substitute for compliance with any requirement of part 3 of Title 37 of CFR to have an assignment recorded by the Office.

Applicant 1 Remove

If the applicant is the inventor (or the remaining joint inventor or inventors under 37 CFR 1.45), this section should not be completed. The information to be provided in this section is the name and address of the legal representative who is the applicant under 37 CFR 1.43; or the name and address of the assignee, person to whom the inventor is under an obligation to assign the invention, or person who otherwise shows sufficient proprietary interest in the matter who is the applicant under 37 CFR 1.46. If the applicant is an applicant under 37 CFR 1.46 (assignee, person to whom the inventor is obligated to assign, or person who otherwise shows sufficient proprietary interest) together with one or more joint inventors, then the joint inventor or inventors who are also the applicant should be identified in this section. Clear

● Assignee	Legal Representative under 35 U.S.C. 117	Joint Inventor
Person to whom the inventor is obligated to assign.	Person who shows sufficient proprietary interest	

If applicant is the legal representative, indicate the authority to file the patent application, the inventor is:

Name of the Deceased or Legally Incapacitated Inventor:

If the Applicant is an Organization check here. ☒

Organization Name	Telefonaktiebolaget LM Ericsson (publ)		
Mailing Address Information For Applicant:			
Address 1	SE-164 83		
Address 2			
City	Stockholm	**State/Province**	
Country	SE	Postal Code	
Phone Number		Fax Number	
Email Address			

Additional Applicant Data may be generated within this form by selecting the Add button. Add

Assignee Information including Non-Applicant Assignee Information:

Providing assignment information in this section does not substitute for compliance with any requirement of part 3 of Title 37 of CFR to have an assignment recorded by the Office.

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	4015-9595 / P45698-US2
	Application Number	

Title of Invention	Codebook Subset Restriction Signaling

Assignee 1

Complete this section if assignee information, including non-applicant assignee information, is desired to be included on the patent application publication. An assignee-applicant identified in the "Applicant Information" section will appear on the patent application publication as an applicant. For an assignee-applicant, complete this section only if identification as an assignee is also desired on the patent application publication.

Remove

If the Assignee or Non-Applicant Assignee is an Organization check here. ☐

Prefix	**Given Name**	Middle Name	**Family Name**	Suffix

Mailing Address Information For Assignee including Non-Applicant Assignee:

Address 1			
Address 2			
City		**State/Province**	
Country		Postal Code	
Phone Number		Fax Number	
Email Address			

Additional Assignee or Non-Applicant Assignee Data may be generated within this form by selecting the Add button. Add

Signature:

Remove

NOTE: This Application Data Sheet must be signed in accordance with 37 CFR 1.33(b). **However, if this Application Data Sheet is submitted with the INITIAL filing of the application and either box A or B is not checked in subsection 2 of the "Authorization or Opt-Out of Authorization to Permit Access" section, then this form must also be signed in accordance with 37 CFR 1.14(c).**

This Application Data Sheet **must** be signed by a patent practitioner if one or more of the applicants is a **juristic entity** (e.g., corporation or association). If the applicant is two or more joint inventors, this form must be signed by a patent practitioner, **all** joint inventors who are the applicant, or one or more joint inventor-applicants who have been given power of attorney (e.g., see USPTO Form PTO/AIA/81) on behalf of **all** joint inventor-applicants.

See 37 CFR 1.4(d) for the manner of making signatures and certifications.

Signature	/ Justin J. Leonard /			Date (YYYY-MM-DD)	2016-06-17
First Name	Justin	Last Name	Leonard	Registration Number	60986

Additional Signature may be generated within this form by selecting the Add button. Add

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	4015-9595 / P45698-US2
	Application Number	
Title of Invention	Codebook Subset Restriction Signaling	

Privacy Act Statement

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The information provided by you in this form will be subject to the following routine uses:

1. The information on this form will be treated confidentially to the extent allowed under the Freedom of Information Act (5 U.S.C. 552) and the Privacy Act (5 U.S.C. 552a). Records from this system of records may be disclosed to the Department of Justice to determine whether the Freedom of Information Act requires disclosure of these records.
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CODEBOOK SUBSET RESTRICTION SIGNALING

RELATED APPLICATIONS

This application claims priority to U.S. Provisional patent Application Serial Number 62/103,101 filed January 14, 2015, the entire contents of which are incorporated herein by reference.

TECHNICAL FIELD

The present application relates generally to a network node and a wireless communication device for operation in a wireless communication system, and more particularly to the network node signaling to the wireless communication device which precoders in a codebook are restricted from being used.

BACKGROUND

The use of multiple antennas at the transmitter and/or the receiver of a wireless communication system can significantly boost the capacity and coverage of a wireless communication system. Such MIMO systems can exploit the spatial dimension of the communication channel. For example, several information-carrying signals can be sent in parallel using the transmit antennas and still be separated by signal processing at the receiver. By adapting the transmission to the current channel conditions, significant additional gains can be achieved. One form of adaptation is to dynamically, from one TTI to another, adjust the number of simultaneously transmitted information streams carrying signals to what the channel can support. This is commonly referred to as (transmission) rank adaptation. Precoding is another form of adaptation where the phases and amplitudes of the aforementioned signals are adjusted to better fit the current channel properties. The signals form a vector-valued signal and the adjustment can be thought of as multiplication by a precoder matrix. A common approach is to select the precoder matrix from a finite and indexed set, a so-called codebook. Such codebook-based precoding is an integral part of the LTE standard, as well as in many other wireless communication standards.

Codebook based precoding can be regarded as a form of channel quantization. A typical approach (c.f. LTE and MIMO HSDPA) is to let the receiver recommend a suitable precoder matrix to the transmitter by signaling the precoder matrix indicator (PMI) over a feedback link. To limit signaling overhead, it is generally important to keep the codebook size as small as possible if the feedback link has a limited capacity. This however needs to be balanced against the performance impact since with a larger codebook it is possible to better match the current channel conditions.

For example, in the LTE downlink, the user equipment (UE) reports the precoding matrix indicator (PMI) to the eNodeB either periodically on the physical uplink control channel (PUCCH) or aperiodic on the physical uplink shared channel (PUSCH). The former is a rather narrow bit pipe (e.g., using a few bits) where channel state information (CSI) feedback is reported in a semi-statically configured and periodic fashion. CSI feedback in this regard includes one or more channel quality indicators (CQIs), PMIs, and/or a transmission rank (e.g., indicating a number of transmission layers). On the other hand, reporting on PUSCH is dynamically triggered as part of the uplink grant. Thus, the eNodeB can schedule CSI transmissions in a dynamic fashion. In contrast to the PUCCH where the number of physical bits is currently limited to 20, the reports on PUSCH can be considerably larger. Thus, for feedback on PUCCH a small codebook size is desirable to keep the signaling overhead down. However, for feedback on PUSCH a larger codebook size is desirable to increase performance, since the capacity on the feedback channel is not as limited in this case.

The desired size of the codebook may also depend on the transmission scheme used. For example, a codebook used in multi-user multiple input multiple output (MU-MIMO) operation could benefit more from having a larger number of elements than a codebook used in single-user multiple input multiple output (SU-MIMO) operation. In the former case, a large spatial resolution is important to allow for sufficient UE separation.

A convenient way to support different codebook sizes is to use a large codebook with many elements by default and apply codebook subset restriction in the scenarios where a smaller codebook is beneficial. With codebook subset restriction, a subset of the precoders in the codebook is restricted so that the UE has a smaller set of possible precoders to choose from. This effectively reduces the size of the codebook implying that the search for the best PMI can be done on the smaller unrestricted set of precoders, thereby also reducing the UE computational requirements for this particular search.

Typically, the eNodeB would signal the codebook subset restriction to the UE by means of a bitmap in an a dedicated message part of the AntennaInfo information element (see the RRC specification, TS 36.331), one bit for each precoder in the codebook, where a 1 would indicate that the precoder is restricted (meaning that the UE is not allowed to choose and report said precoder). Thus, for a codebook with N elements, a bitmap of length N would be used to signal the codebook subset restriction. This allows for full flexibility for the eNodeB to restrict every possible subset of the codebook. There are thus 2^N possible codebook subset restriction configurations.

For large antenna arrays with many antenna elements, the effective beams become narrow and a codebook containing many precoders is required for the intended coverage area. Furthermore, for two-dimensional antenna arrays, the codebook size increases quadratically since the precoders in the codebook need to span two dimensions, typically the horizontal and vertical domain. Thus, the codebook size (i.e. the total number of possible precoding matrices

W) can be very large. Signaling a codebook subset restriction in the conventional way by means of a bitmap with one bit for every precoder can thus impose a large overhead, especially if the codebook subset restriction (CSR) is frequently updated or if there are many users served by the cell which each has to receive the CSR.

SUMMARY

One or more embodiments herein include a method implemented by a network node for signaling to a wireless communication device which precoders in a codebook are restricted from being used. The method comprises generating codebook subset restriction signaling that, for each of one or more groups of precoders, jointly restricts the precoders in the group by restricting a certain component that the precoders in the group have in common. The method further comprises sending the generated signaling from the network node to the wireless communication device.

Embodiments herein also correspondingly include a method implemented by a wireless communication device for decoding signaling from a network node indicating which precoders in a codebook are restricted from being used. The method comprises receiving codebook subset restriction signaling that, for each of one or more groups of precoders, jointly restricts the precoders in the group by restricting a certain component that the precoders in the group have in common. The method further comprises decoding the received signaling as jointly restricting precoders in each of the one or more groups of precoders.

In some embodiments, the codebook subset restriction signaling is rank-agnostic signaling that jointly restricts the precoders in a group without regard to the precoders' transmission rank.

In some embodiments, the certain component comprises a beam precoder. In some embodiments, for example, a beam precoder is a Kronecker product of different beamforming vectors associated with different dimensions of a multi-dimensional antenna array. In this case, the different beamforming vectors may comprise Discrete Fourier Transform (DFT) vectors.

In other embodiments where the certain component comprises a beam precoder, a beam precoder is a beamforming vector used to transmit on a particular layer of a multi-layer transmission. Different scaled versions of that beamforming vector are transmitted on different polarizations.

In still other such embodiments, a beam precoder is a beamforming vector used to transmit on: multiple different layers of a multi-layer transmission; multiple different layers of a multi-layer transmission, wherein the layers are sent on orthogonal polarizations; or a particular layer and on a particular polarization.

In some embodiments, a precoder comprising one or more beam precoders is restricted if at least one of its one or more beam precoders is restricted.

In any of these embodiments, the codebook subset restriction signaling may comprise a bitmap, with different bits in the bitmap respectively dedicated to indicating whether or not

different beam precoders are restricted from being used.

Alternatively or additionally, a beam precoder may be a Kronecker product of first and second beamforming vectors with first and second indices. In this case, the first and second beamforming vectors may be associated with different dimensions of a multi-dimensional antenna array, and the codebook subset restriction signaling may jointly restrict the precoders in a group of precoders that have the same pair of values for the first and second indices.

In some embodiments, each precoder comprises one or more beam precoders. In some of these embodiments, each beam precoder comprises multiple different components corresponding to different dimensions of a multi-dimensional antenna array. The certain component in this case may comprise a component of a beam precoder.

In some embodiments, the codebook subset restriction signaling jointly restricts the precoders in a group of precoders that transmit at least in part towards a certain angular pointing direction, by restricting a certain component which has that angular pointing direction.

Embodiments herein also include another method implemented by a network node for signaling to a wireless communication device which precoders in a codebook are restricted from being used. The method comprises a number of steps for each of one or more groups of precoders in the codebook. These steps include identifying one or more reference configurations for the group. Each reference configuration is one of different possible configurations that restrict different subgroups of precoders in the group from being used. The steps also include identifying, from the different possible configurations for the group, an actual configuration to be signaled for the group. The steps also include generating signaling to indicate the actual configuration for the group, by generating the signaling as a bit pattern whose length depends on (i) whether the actual configuration matches one of the one or more reference configurations and/or (ii) which reference configuration the actual configuration matches. The method further comprises sending the generated signaling to the wireless communication device.

Embodiments herein further include another corresponding method implemented by a wireless communication device for decoding signaling from a network node indicating which precoders in a codebook are restricted from being used. The method includes receiving signaling from the network node. The method also entails a number of steps for each of one or more groups of precoders in the codebook. These steps include identifying one or more reference configurations for the group. Each reference configuration is one of different possible configurations that restrict different subgroups of precoders in the group from being used. The steps further include identifying a bit pattern defined for signaling each reference configuration, and a length of that bit pattern. The steps also include detecting an actual configuration signaled for the group, by detecting in the signaling a bit pattern whose length depends on (i) whether the actual configuration matches one of the one or more reference configurations and/or (ii) which reference configuration the actual configuration matches.

In some embodiments, the signaling is a short bit pattern when the actual configuration matches any one of the one or more reference configurations and is a long bit pattern when the actual configuration does not match any of the one or more reference configurations. A long bit pattern has more bits than a short bit pattern. In this case, the one or more reference configurations for at least one of the one or more groups may comprise a single reference configuration, and different long bit patterns may be respectively defined for signaling different configurations other than the single reference configuration. Alternatively or additionally, a long bit pattern defined for signaling the actual configuration for the group may comprise: (i) a non-reference bit pattern defined for signaling that the actual configuration does not match a reference configuration for the group; and (ii) a bitmap comprising different bits respectively dedicated to indicating whether different precoders in the group are restricted from being used.

In some embodiments, the one or more reference configurations for at least one of the one or more groups comprise multiple reference configurations. In this case, when the actual configuration matches a particular one of the multiple reference configurations, the signaling is a bit pattern whose length is shorter than that of a bit pattern generated when the actual configuration matches a different one of the multiple reference configurations.

In some embodiments, the one or more reference configurations for a group each have an actual or assumed higher probability of being signaled than any other possible configuration that is not one of the one or more reference configurations.

In some embodiments, the method is performed for multiple different groups that respectively include different portions of the precoders in the codebook. In this case, the signaling indicates the actual configurations for the groups in a defined order. The one or more reference configurations for each group comprises a single reference configuration, and the single reference configuration for any given group is the actual configuration, if any, signaled immediately before that of the given group.

In some embodiments, the codebook is a Kronecker codebook defined for a multi-dimensional antenna array and comprises different precoders indexed by different possible values of a single index parameter. In this case, the different possible values of the single index parameter are divided into different clusters of consecutively ordered values, and precoders in different ones of the one or more groups are respectively indexed by the different clusters of consecutively ordered values.

In some embodiments, the codebook is a Kronecker codebook defined for a multi-dimensional antenna array and comprises different precoders indexed by different pairs of possible values for a first-dimension index parameter and a second-dimension index parameter. In this case, precoders in each of the one or more groups are indexed by pairs that have the same value for either the first-dimension index parameter or the second-dimension index parameter.

Embodiments herein further include corresponding apparatus and computer program products.

In at least some embodiments, signaling a codebook subset restriction in this way advantageously lowers the signaling overhead imposed by transmitting the codebook subset restriction, while still allowing for flexibility in configuring different codebook subset restrictions.

Embodiments herein therefore generally include methods to reduce the number of bits required for signaling a codebook subset restriction configuration to a wireless communication device. The methods in one or more of these embodiments do so by:

Utilizing an explicit or implicit assumption about which sets of precoders are more likely to be restricted, and/or associating a group of precoders with a single codebook subset restriction bit.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a logic flow diagram indicating codebook subset restriction (CSR) signaling between a network node and a wireless communication device according to one or more embodiments.

Figure 2 is a logic flow diagram of a method implemented by a network node for signaling to a wireless communication device which precoders in a codebook are restricted from being used, according to some embodiments.

Figure 3 is a block diagram of a two-dimensional antenna array of cross-polarized antenna elements according to some embodiments.

Figure 4 is a graph illustrating the angular pointing directions of precoders in a codebook according to some embodiments.

Figure 5 is a logic flow diagram of a method implemented by a network node for signaling to a wireless communication device which precoders in a codebook are restricted from being used, according to other embodiments.

Figure 6 is a block diagram of an exemplary codebook according to some embodiments.

Figure 7 is a graph illustrating the angular pointing directions of precoders in a codebook according to other embodiments.

Figure 8 is a block diagram of precoder groupings according to some embodiments.

Figure 9 is a logic flow diagram of a method implemented by a wireless communication device for decoding signaling from a network node indicating which precoders in a codebook are restricted from being used, according to some embodiments.

Figure 10 is a logic flow diagram of a method implemented by a wireless communication device for decoding signaling from a network node indicating which precoders in a codebook are restricted from being used, according to other embodiments.

Figure 11 is a block diagram of a network node according to some embodiments.

Figure 12 is a block diagram of a network node according to other embodiments.

Figure 13 is a block diagram of a wireless communication device according to some embodiments.

Figure 14 is a block diagram of a wireless communication device according to other embodiments.

DETAILED DESCRIPTION

According to the flowchart of Figure 1, a network node 10 in a wireless communication network (e.g., an eNB in the network) signals a codebook subset restriction (CSR) configuration 12 to a wireless communication device 14 (e.g., a UE). The device 14 then sends a channel state information (CSI) report 16 back to the network. This CSI report 16 suggests which of different possible precoders in a codebook the network should use for transmitting to the device 14, but the CSI report 16 is restricted in the sense that there is a subset of precoders that cannot be reported by the device 14; that is, all precoders in the codebook cannot be selected and reported by the device 14. This restriction is defined by the signaled CSR configuration 12.

In more detail, for a precoder codebook X, consisting of N precoders, there are 2^N possible codebook subset restriction configurations since each precoder can individually either be allowed or restricted (a restricted configuration is not allowed to be used). Each configuration can be represented by a bitmap of N bits, where each bit corresponds to a certain precoder and the value of the bit then indicates whether the precoder is restricted or not. If each of the 2^N configurations is equiprobable and independent, this is the optimal representation of a codebook subset restriction configuration with respect to the expected length (in bits) of the representation and it provides full flexibility.

However, embodiments herein recognize that, if certain configurations are more likely to be used than others, and/or if the restriction of one precoder is highly correlated to the restriction of another precoder, then this signaling leads to unnecessarily high signaling overhead. One or more embodiments herein include methods to reduce this signaling overhead; that is, reduce the number of bits required for signaling a codebook subset restriction configuration to a wireless communication device 14 from the network. In some embodiments, for example, the methods utilize an implicit assumption about which sets of precoders are more likely to be restricted or which sets of precoders are likely to be jointly restricted.

According to one embodiment shown in Figure 2, for example, a method is implemented by a network node 10 (e.g., a base station) for signaling to a wireless communication device 14 which precoders in a codebook are restricted from being used. For each of one or more groups of precoders in the codebook, the method includes identifying one or more reference configurations for the group (Block 110). Each reference configuration is one of different possible configurations that restrict different subgroups of precoders in the group from being used. One of the reference configurations for a group may be for instance whichever one of the different possible configurations has the maximum probability of being signaled, e.g., as predicted or estimated based on empirical observations or implicit assumptions. Regardless, the method further includes identifying, from the different possible configurations for the group, the actual configuration to be signaled for the group (Block 120).

The method also includes generating signaling to indicate the actual configuration for the group (Block 130). This entails generating the signaling as a bit pattern whose length depends on (i) whether the actual configuration matches one of the one or more reference configurations; and/or (ii) which reference configuration the actual configuration matches. In some embodiments, for example, when the actual configuration matches any reference configuration, the bit pattern's length is shorter than when the actual configuration does not match any reference configuration. In other embodiments, when the actual configuration matches a particular one of multiple reference configurations, the bit pattern's length is shorter than when the actual configuration matches a different one of the reference configurations. Regardless, this process (Blocks 110-130) is repeated for each of one or more groups of precoders in the codebook (Blocks 100, 140, and 150). Finally, the method includes sending the generated signaling to the wireless communication device 14 (Block 160).

This approach may in some sense be viewed as a sort of compression algorithm for CSR signaling. Indeed, the approach advantageously reduces the signaling overhead when, over the course of a given time period, the overhead savings realized by signaling bit patterns with relatively shorter lengths outweighs the overhead costs imposed by signaling bit patterns with relatively longer lengths. Depending on the relative lengths of the bit patterns, then, the approach may for instance reduce signaling overhead when the one or more reference configurations (or particular ones of the one or more reference configurations) are signaled more often than not.

In at least some embodiments, therefore, a reference configuration has a higher likelihood or probability of being signaled than any other possible configurations that are not reference configurations. For example, the one or more reference configurations for a group may include whichever one(s) of the different possible configurations for the group have the highest probability of being signaled. Different reference configurations that have different probabilities of being signaled may be represented with bit patterns of different lengths, where reference configurations with higher probabilities are represented with bit patterns of shorter lengths. That is, certain configurations that are deemed more probable may be represented with a fewer number of bits, while other configurations, that are deemed less probable to be used, may be represented with a larger number of bits.

In some embodiments, the one or more reference configurations may be predefined to be particular one(s) of the possible configurations, e.g., based on an (implicit) assumption that the particular configuration(s) have the highest probability of being signaled. For example, an implicit assumption is made on how the network is likely to be configured. Hence, here certain configurations are considered more likely than others but there are no actual probability values estimated for the different configurations.

In other embodiments, though, the network node 10 determines signaling probabilities of different configurations, e.g., based on empirical observations and compares those probabilities to identify the configuration(s) with the highest probability. In one embodiment for example signaling probabilities are estimated through logging of network data. Hence, here it may be possible to estimate actual probabilities for the different configurations. In general, therefore, the knowledge on "how likely" a certain configuration is may be obtained in many ways.

In some embodiments, only a single reference configuration is defined for a group. In this case, the signaling is generated as a short bit pattern when the actual configuration matches the reference configuration and as a long bit pattern when the actual configuration does not match the reference configuration. Different long bit patterns in this regard are respectively defined for signaling different configurations (other than the reference configuration, for which the short bit pattern is defined for signaling). A long bit pattern of course has more bits than a short bit pattern (e.g., N bits vs. 1 bit).

In other embodiments, multiple reference configurations are defined for a group. In this case, the signaling may be generated as bit patterns that have different lengths when the actual configuration matches different reference configurations. These lengths may correspond to how likely it is that the reference configurations will be signaled. The bit pattern's length may be shortest when the actual configuration matches a particular one of the reference configurations (e.g., the one with the maximum probability of being signaled), may be next shortest when the actual configuration matches a different reference configuration (e.g., the one with the next highest signaling probability), and may be longest when the actual configuration does not match any of the reference configurations.

In some embodiments, bit patterns signaling non-reference configurations are encoded as a combination of a so-called "non-reference bit pattern" and a "bitmap." The non-reference bit pattern is defined for signaling that the actual configuration for the group does not match any reference configuration for the group. The non-reference bit pattern may for instance be the complement of a bit pattern defined for signaling a reference configuration. For example, when only a single reference configuration is defined for a group, the bit pattern signaling that reference configuration may simply be a single bit with a value of "1", whereas the non-reference bit pattern may be a single bit with a value of "0". Regardless, the bitmap portion of the bit pattern comprises different bits respectively dedicated to indicating whether different precoders in the group are restricted from being used.

In at least some embodiments, the method is performed for only one group. This single group in one embodiment includes all precoders in the codebook.

In another embodiment, of course, the single group includes only a portion of the precoders in the codebook, such that the signaling approach is adopted for only this portion, while other signaling approaches (e.g., the conventional bitmap) is adopted for other portions.

In other embodiments, the method is performed for multiple different groups that respectively include different portions of the precoders in the codebook. In one such embodiment, the signaling indicates the actual configurations for the groups in a defined order. In one embodiment, the one or more reference configurations for any given group includes the actual configuration, if any, signaled immediately before that of the given group (according to the defined order).

Consider an example with an arbitrary codebook of size N, where the single group includes all N precoders. A certain configuration out of the 2^N possible codebook subset restriction configurations for the single group is deemed more probable. This configuration is represented by a single bit, '1'. The other $2^N - 1$ configurations are represented by a '0', followed by a bitmap of size N. One of the configurations is then represented by 1 bit, while the other configurations are represented by $N + 1$ bits. Since the configuration represented by one bit is more frequently signaled, according to the assumption, the average number of bits required to convey the codebook subset restriction may be much less than N.

However, if the assumption that one of the possible codebook subset restriction configurations was more likely than the others was incorrect for the actual usage of codebook subset restriction configurations, the average number of bits required to convey a codebook subset restriction to a UE may be larger than N bits. One or more embodiments herein therefore aim to choose the representations of the 2^N configurations well. Various methods may represent the 2^N configurations differently depending on which sets of precoders are more likely to be restricted.

Consider for example embodiments where the codebook is defined for a multi-dimensional (e.g., two-dimensional) antenna array. Such antenna arrays may be (partly) described by the number of antenna columns corresponding to the horizontal dimension M_h, the number of antenna rows corresponding to the vertical dimension M_v and the number of dimensions corresponding to different polarizations M_p The total number of antennas is thus $M = M_h M_v M_p$. It should be pointed out that the concept of an antenna is non-limiting in the sense that it can refer to any virtualization (e.g., linear mapping) of the physical antenna elements. For example, pairs of physical sub-elements could be fed the same signal, and hence share the same virtualized antenna port.

An example of a 4x4 array with cross-polarized antenna elements is illustrated in Figure 3. Specifically, Figure 3 shows a two-dimensional antenna array of cross-polarized antenna elements ($M_P = 2$), with $M_h = 4$ horizontal antenna elements and $M_v = 4$ vertical antenna elements, assuming one antenna element corresponds to one antenna port.

Precoding may be interpreted as multiplying the signal with different beamforming weights for each antenna prior to transmission. A typical approach is to tailor the precoder to the antenna form factor, i.e. taking into account M_h, M_v and M_p when designing the precoder codebook.

According to some embodiments, a precoder codebook is tailored for 2D antenna arrays by combining precoders tailored for a horizontal array and a vertical array respectively by means of a Kronecker product. This means that (at least part of) the precoder can be described as a function of

$$W_H \otimes W_V$$

where W_H is a horizontal precoder taken from a (sub)-codebook X_H containing N_H codewords and similarly W_V is a vertical precoder taken from a (sub)-codebook X_V containing N_V codewords. The joint codebook, denoted $X_H \otimes X_V$, thus contains $N_H \cdot N_V$ codewords. The elements of X_H are indexed with $k = 0, \ldots, N_H - 1$, the elements of X_V are indexed with $l = 0, \ldots, N_V - 1$ and the elements of the joint codebook $X_H \otimes X_V$ are indexed with $m = N_V \cdot k + l$ meaning that $m = 0, \ldots, N_H \cdot N_V - 1$.

In some embodiments, for example, the (sub)-codebooks of the Kronecker codebook consist of DFT-precoders. In this case, the horizontal codebook can be expressed as $X_H^k = \left[1 \ e^{j2\pi\frac{1k+\Delta_h}{M_h Q_h}} \ \cdots \ e^{j2\pi\frac{(M_h-1)k+\Delta_h}{M_h Q_h}}\right]^T$, $k = 0, \ldots, M_h Q_h - 1$, where Q_h is an integer horizontal oversampling factor and Δ_h can take on value in the interval 0 to 1 so as to "shift" the beam pattern (Δ_h =0.5 could be an interesting value for creating symmetry of beams with respect to the broadside of an array). And the vertical codebook can be expressed as $X_V^l = \left[1 \ e^{j2\pi\frac{1l+\Delta_v}{M_v Q_v}} \ \cdots \ e^{j2\pi\frac{(M_v-1)l+\Delta_v}{M_v Q_v}}\right]^T$, $l = 0, \ldots, M_v Q_v - 1$, where Q_v is an integer vertical oversampling factor and Δ_v is similarly defined as above.

It should be pointed out that a precoder codebook may be defined in several ways. For example, the above mentioned Kronecker codebook may be interpreted as one codebook indexed with a single PMI m. Alternatively, it may be interpreted as a single codebook indexed with two PMIs k and l. It may also be interpreted as two separate codebooks, indexed with k and l respectivly. Further, the Kronecker codebook discussed above may only describe a part of the precoder, i.e. the precoder may be a function of other parameters as well. In a such example, the precoder is a function also of another PMI n. Again, this can be interpreted as three separate codebooks with indices k, l and n respectively, or two separate codebooks with indices $m = N_V \cdot k + l$ and n respectivly. It may also be interpreted as a single joint codebook with a joint PMI. Embodiments herein should be considered agnostic with respect to how a codebook is defined.

With this understanding, the codebook at issue in Figure 2 may be a Kronecker codebook that comprises different precoders indexed (at least in part) by different possible values of a single index parameter (e.g., index parameter $m = 0, \ldots, N_H \cdot N_V - 1$). In this case, the different possible values of the single index parameter are divided into different clusters of consecutively ordered values. And precoders in the different groups are respectively indexed (at least in part) by the different clusters of consecutively ordered values. For example, precoders indexed by the cluster $m = 0, \ldots m1$ belong to a first group, precoders indexed by the cluster $m = m2, \ldots m3$ belong to a second group, precoders indexed by the cluster $m = m4, \ldots m5$ belong to a third group, and so on. As an even more specific example, one or more embodiments exploit the Kronecker structure of the precoder by mapping the index m to indices k and l as $m = N_v k + l$ and grouping the precoders such that m = 0,...,Nv-1 is the first group, m= Nv,...,2Nv-1 is the second group , etc.

In another embodiment, by contrast, the Kronecker codebook comprises different precoders indexed (at least in part) by different pairs of possible values for a first-dimension index parameter (e.g., $k = 0, \ldots, N_H - 1$) and a second-dimension index parameter (e.g., $l = 0, \ldots, N_V - 1$). In this case, precoders in each of the different groups are indexed (at least in part) by pairs (k, l) that have the same value for the first-dimension index parameter k and/or the second-dimension index parameter l.

Two different embodiments in this regard, referred to as a "similar rows embodiment" and a "similar columns embodiment", will now be illustrated in the context of a Kronecker codebook and where only a single reference configuration is defined for a group. The Kronecker codebook in this example consists of precoders with different angular directions, spanning a two-dimensional angular area as seen from the transmitter. An important use case for codebook subset restriction in such an embodiment may be to restrict precoders in a certain angular area or angle interval, e.g. corresponding to a direction where a user hotspot of an adjacent cell is located. The eNodeB would then reduce interference to said adjacent cell and particular the hotspot area if precoders corresponding to beams pointing at that direction were restricted. This is beneficial from a system capacity perspective.

In the following, consider the specific example where codebook subset restriction is used on a Kronecker codebook in order to understand how different embodiments can be used to reduce the signaling overhead. In this scenario, a 4x4 antenna array with a mechanical downtilt of 18° is used. The Kronecker codebook consists of 8 vertical and 8 horizontal precoders, i.e. $N_H = N_V = 8$. The angular pointing directions of the precoders in the codebook are illustrated in Figure 4.

Codebook subset restriction is applied to restrict beams with pointing directions in the zenith interval $[85^\circ, 95^\circ]$ (illustrated with dotted lines). That is, codebook subset restriction is applied in the angular interval $85^\circ < \theta < 95^\circ$, meaning that the precoders with indices $(k, l) = (0,4), (3,5), (4,5), (7,4)$ are restricted. These restricted beams are illustrated with an 'o' while the unrestricted beams are illustrated with an 'x'. The beam index k in the horizontal codebook and l in the vertical codebook is written next to the beams as (k, l). If this configuration of codebook subset restriction would be signaled with a conventional bitmap, $N = N_H \cdot N_V = 64$ bits would be used.

"Similar rows embodiment"

In one embodiment, by using compressing of the CSR signalling, a scheme is designed taking into consideration the hypothesis that precoders (k, l) with adjacent l-indices (i.e. $(k, l_0 - 1), (k, l_0)$ and $(k, l_0 + 1)$) are likely to have the same restriction setting, meaning that if (k, l_0) is restricted, $(k, l_0 + 1)$ is likely to be restricted as well and vice versa. The scheme works as follows:

First, a bitmap of N_H bits are sent, indicating the codebook subset restriction for the "row" of precoders where $l = 0$ (c.f. Figure 4), i.e the precoders $(k, l) = (0,0), (1,0), \ldots, (N_H - 1,0)$.

Then, the codebook subset restriction for the second "row" of precoders, where $l = 1$ is sent. If the restriction is the same as for the previous row of precoders, a '1' is sent. If the restriction for this row differs from the restriction of the previous row, a '0' is sent, followed by a bitmap indicating the restriction for this row.

The previous step is then repeated for each of the N_V "rows" of precoders.

This embodiment is illustrated with an example, considering the codebook subset restriction setting illustrated in Figure 4, i.e. the restriction of precoders with indices $(k, l) = (0,4), (3,5), (4,5), (7,4)$ should be signaled.

For $l = 0$:

No precoders with l-index 0 should be restricted, therefore the bitmap '00000000' is sent.

For $l = 1$:

The restriction of this row is identical to the restriction of the previous row, the bit '1' is sent.

For $l = 2$:

The restriction of this row is identical to the restriction of the previous row, the bit '1' is sent.

For $l = 3$:

The restriction of this row is identical to the restriction of the previous row, the bit '1' is sent.

For $l = 4$:

The restriction of this row is not identical to the restriction of the previous row, therefore the bit '0' is sent. The bitmap indicating the restriction for this row should now be sent. Precoders $(0,4)$ and $(7,4)$ should be restricted. Therefore, the bitmap '10000001' is sent.

For $l = 5$:

The restriction of this row is not identical to the restriction of the previous row, therefore the bit '0' is sent. The bitmap indicating the restriction for this row should now be sent. Precoders (3,5) and (4,5) should be restricted. Therefore, the bitmap '00011000' is sent.

For $l = 6$:

The restriction of this row is not identical to the restriction of the previous row, therefore the bit '0' is sent. The bitmap indicating the restriction for this row should now be sent. No precoder should be restricted. Therefore, the bitmap '00000000' is sent.

For $l = 7$:

The restriction of this row is identical to the restriction of the previous row, the bit '1' is sent.

The string of bits to be signaled is thus 000000000111010000001000011000000000001', consisting of 39 bits. Generally, the number of bits required with this scheme is

$$N_{bits} = M \cdot N_H + N_V - 1$$

Where M is the number of times the rows change and a bitmap for a row has to be transmitted, $M = 4$ in the example. Analyzing the above expression, we note that $1 \leq M \leq N_V$. This means that for some of the $2^N = 2^{N_H \cdot N_V}$ possible codebook subset restrictions, the number of bits required to signal the codebook subset restriction with this scheme is smaller than N, while for others, such as when $M = N_V$, the number of bits required is larger than N.

It should be noted that this is a small example for the sake of illustrating the embodiment. If a larger codebook is used, say $N_H = N_V = 30$, and $M = 4$ the number of bits required with this scheme would be $N_{bits} = M \cdot N_H + N_V - 1 = 149$ compared to $N = N_H \cdot N_V = 900$ in the case of just transmitting the entire bitmap; this is hence a substantial reduction in the number of required bits.

Finally, it is pointed out that all possible codebook subset restriction configurations can be represented by this encoding/decoding scheme, thereby providing full flexibility.

"Similar columns" embodiment

In another embodiment, the scheme discussed in the previous embodiment is modified by instead taking into consideration the hypothesis that precoders (k, l) with adjacent k-indices (i.e. $(k_0 - 1, l), (k_0, l)$ and $(k_0 + 1, l)$) are likely to have the same restriction setting, meaning that if (k_0, l) is restricted, $(k_0 + 1, l)$ is likely to be restricted as well and vice versa. The construction of the string of bits to be signaled would then work similarly as in the previously discussed embodiment, except that the precoders "columns" k will be used instead.

In another embodiment an extra initial bit is inserted where '1' indicates that encoding is done under the assumption that precoders (k, l) with adjacent l-indices (i.e. $(k, l_0 - 1), (k, l_0)$ and $(k, l_0 + 1)$) are likely to have the same restriction, hence the encoding is done row wise, whereas a '0' indicates that precoders (k, l) with adjacent k-indices (i.e. $(k_0 -$

$1, l), (k_0, l)$ and $(k_0 + 1, l)$) are likely to have the same restriction setting, hence encoding is done column wise.

In another embodiment an initial bit is inserted where '1' indicates that no precoders are restricted, a '0' indicates that some precoders are restricted and the '0' is followed by a number of bits representing the codebook subset restriction.

Accordingly, different "compression" techniques (whether based on similar rows, columns, or otherwise) may be adopted for different groups of precoders in the same codebook, where the particular technique is indicated to the device so that the device can decode the signaling. Alternatively, the same "compression" technique may be adopted for each of the groups of precoders, but the network evaluates different possible techniques to identify the one that provides the best compression and then adopts that approach (and indicates it to the device).

Of course, the embodiments shown in Figure 2, and variations thereof, may be used for signaling a restricted subset of precoders in any given codebook, whether Kronecker structured or not. Moreover, the signaling may be rank-specific, meaning that different signaling restricts different rank-specific codebooks.

According to other embodiments shown in Figure 5, a method is implemented in a network node 10 (e.g., a base station) for signaling to a wireless communication device 14 which precoders in a codebook are restricted from being used (e.g., which Kronecker product precoders are restricted). As shown, the method includes generating codebook subset restriction signaling that, for each of one or more groups of precoders, jointly restricts the precoders in the group, e.g., with a single signaling bit (Block 210). In at least some embodiments, this signaling (i) is rank-agnostic so as to restrict precoders irrespective of their transmission rank; and/or (ii) jointly restricts a group of precoders by restricting a certain component that those precoders (i.e., the precoders in the group) have in common. Regardless, the method then includes sending the generated signaling to the wireless communication device 14 (Block 220).

Consider embodiments that jointly restrict a group of precoders by restricting a certain component that those precoders (i.e., the precoders in the group) have in common. Precoders have a certain component in common if the precoders are derived from or are otherwise a function of that same component. In one embodiment, for example, a group of precoders $W(b)$ that have a certain component b in common are jointly restricted by restricting that component b. Restriction of this component b may be signaled for instance in terms of one or more indices for the component (e.g., m where the component is indexed as b_m or (k, l) where the component is indexed as $b_{k,l}$, with m, k, and l being indices for a Kronecker-structured codebook as described above).

Note that embodiments herein contemplate a precoder having one or more different "components" at any level of granularity (e.g., component(s) at a high level of precoder factorability and/or component(s) at a lower level of precoder factorability). For example, a precoder may comprise one or more different components b at one level of granularity. At a finer level of granularity, though, each of these components b may in turn be derived from or otherwise be a function of multiple sub-components x_H and x_V such that $b(x_H, x_V)$. In this case, a group of precoders $W(x_H, x_V)$ that have a certain component x_H or x_V in common may be jointly restricted by restricting that component x_H or x_V. Restriction of this component x_H or x_V may be signaled for instance in terms of an index for the component (e.g., k or l where the component x_H is indexed as x_H^k and the component x_V is indexed as x_V^l, with x_H and x_V being horizontal and vertical beamforming vectors, respectively, and with k and l being indices for a Kronecker-structured codebook as described above).

In some embodiments, a precoder at one level of granularity consists of one or more different components that are referred to as one or more so-called "beam precoders". Each precoder W in this regard consists of one or more beamforming vectors $b_0, b_1, \ldots, b_X$ that are referred to as beam precoders. One or more embodiments herein jointly restrict a group of precoders W that have a certain beam precoder in common, by restricting that beam precoder. With restriction of precoders W as a whole founded on restriction of one or more of their constituting beam precoders, these embodiments advantageously generate the CSR signaling in terms of beam-specific restrictions (i.e., restrictions of certain beam precoders), rather than in terms of precoder-specific restrictions (i.e., restrictions on precoders W as a whole). In some embodiments, the device 14 shall assume that a precoder W is restricted if one or more of its beam precoders are restricted. In other embodiments, each beam precoder must be restricted for the device 14 to assume that the total precoder W is restricted.

In one embodiment, a beam precoder is the beamforming vector used to transmit on a particular layer, where different scaled versions of that beamforming vector are transmitted on different polarizations. Different layers are transmitted on different beam precoders. A precoder W in this case can be expressed as:

$$W = \alpha \cdot \begin{bmatrix} b_0 & b_1 & \cdots & b_{L-1} \\ \varphi_0 b_0 & \varphi_1 b_1 & \cdots & \varphi_{L-1} b_{L-1} \end{bmatrix}$$

Here, W is a $N \times L$ precoder matrix, where N is the number of transmit antenna ports, L the transmission rank (i.e. the number of transmitted spatial streams), $b_0, b_1, \ldots, b_{L-1}$ are $\frac{N}{2} \times 1$ beamforming vectors (denoted beam precoders), $\varphi_0, \varphi_1, \ldots, \varphi_{L-1}$ and α are arbitrary complex numbers. Another precoder W of the same codebook as W above can be expressed as:

$$W = \alpha \cdot \begin{bmatrix} b_1 & b_2 & \cdots & b_L \\ \varphi_1 b_1 & \varphi_2 b_2 & \cdots & \varphi_L b_L \end{bmatrix}.$$

For example, by signaling b_0 only the former precoder is restricted and by signaling b_1 both precoders will be restricted.

In some embodiments, the first $\frac{N}{2}$ antenna ports are mapped to antennas with one polarization while the latter $\frac{N}{2}$ antenna ports are mapped to antennas with the same positions as the first antennas, but with an orthogonal polarization. In such embodiments, for each column of W (i.e. the precoder for each spatial layer), a beam precoder b is transmitted on one polarization and a scaled version of the same beam precoder φb is transmitted on a second polarization. Such scaling may impact the phase, amplitude, or both the phase and amplitude of the beam precoder.

In another embodiment, a beam precoder is the beamforming vector used to transmit on multiple different layers, where the layers are sent on orthogonal polarizations. In this case, a precoder W can be expressed as:

$$W = \alpha \cdot \begin{bmatrix} b_0 & b_0 & \cdots & b_0 \\ \varphi_0 b_0 & \varphi_1 b_0 & \cdots & \varphi_{L-1} b_0 \end{bmatrix}$$

Accordingly, it should be noted that the beam precoders for each spatial layer $b_0, b_1, \ldots, b_{L-1}$ may be different beam precoders, or, some subsets of the beam precoders may be identical, for example b_0 may be equal to b_1.

In yet another embodiment, a beam precoder is the beamforming vector used to transmit on a particular layer and on a particular polarization. That is, a beam precoder may be defined in a slightly different way than the definition above. The definition of a beam precoder may for example allow different beam precoders to be transmitted on the different polarizations of the same layer, such as

$$W = \alpha \cdot \begin{bmatrix} b_0 & b_2 & \cdots & b_{2L-2} \\ \varphi_0 b_1 & \varphi_1 b_3 & \cdots & \varphi_{L-1} b_{2L-1} \end{bmatrix}.$$

In still another embodiment, the beam precoders may be defined by disregarding the polarization as

$$W = \alpha \cdot [b_0 \quad b_1 \quad \ldots \quad b_{L-1}].$$

Note that the beam precoders $b_0, b_1, \ldots, b_{L-1}$ may be chosen explicitly from a set of beam precoders (a codebook) or they may be implicitly chosen when selecting the (total) precoder W from a codebook $\boldsymbol{X}$. It should be noted that the selection of the (total) precoder W may be made with one or several PMIs. In the case where selection of the total precoder W is made with several PMIs, the resulting beam precoders for each layer may be a function of only a subset of the PMIs or they may be a function of all PMIs.

Irrespective of the particular way a beam precoder is defined, though, one or more embodiments herein jointly restrict a group of precoders W that have a certain beam precoder in common, by restricting that beam precoder. That is, in some embodiments, codebook subset restriction (CSR) may be signalled based on the set of possible beam precoders b, instead of CSR signalled on the set of possible (total) precoders W. In some such embodiments, the device 14 shall assume that a precoder W is restricted if one or more of the beam precoders

$b_0, b_1, \ldots, b_{L-1}$ of each layer are restricted. In other such embodiments, each layers' beam precoder must be restricted for the device 14 to assume that the total precoder W is restricted.

Consider a specific example for an 8TX codebook with transmission rank 2. In some embodiments, this codebook is defined as shown in Figure 6. Defined in this way, each precoder W is formed in part from a beam precoder v_m (note the notation shift from $b_0, b_1, \ldots, b_{L-1}$ to v_m). The beam precoder index m is the same for some precoders W, including for instance precoders whose subcodebook index i_2 is equal to 0, 1, 8, 9, 12 or 13 (since for those precoders $m = 2i_1$). This means that those precoders W have the same beam precoder v_m in common. Accordingly, some embodiments herein jointly restrict a group of precoders W that have a particular beam precoder v_m in common, by restricting that beam precoder v_m, e.g., with a single bit. Restriction of this beam precoder v_m may be signaled for instance in terms of index m (e.g., beam precoders indexed with a particular value of m are restricted). Signaling in this case may constitute a bitmap, with different bits in the bitmap respectively dedicated to indicating whether or not different beam precoders are restricted from being used. For example, signaling may constitute a bitmap of m values, with different bits in the bitmap respectively dedicated to indicating whether or not beam precoders indexed with different of m values are restricted from use.

In alternative embodiments not shown in Figure 6, the beam precoder v_m is replaced by beam precoder $v_{k,l}$, which is a Kronecker product of a vertical beamforming vector x_V with index k and a horizontal beamforming vector x_H with index l. For example, as noted above, these beamforming vectors may comprise DFT vectors. Regardless, restriction of beam precoder $v_{k,l}$ may be signaled in terms of the index pair (k, l). Signaling in this case may constitute a bitmap of (k, l) value pairs, with different bits in the bitmap respectively dedicated to indicating whether or not beam precoders indexed with different (k, l) value pairs are restricted from use.

Instead of such a bitmap, restriction of one or more beam precoders $v_{k,l}$ in some embodiments is jointly signaled in terms of a "rectangle" defined by two (k, l) value pairs: namely, (k_0, l_0) and (k_1, l_1). In this case, beam precoders $v_{k,l}$ with indides $k_0 < k < k_1$ and $l_0 < l < l_1$ are restricted.

As yet another alternative, restriction of one or more beam precoders $v_{k,l}$ in some embodiments is signaled in terms of a bitmap of k values and/or a bitmap of l values. If signaled as only a bitmap of k values, the device in some embodiments assumes that any beam precoders $v_{k,l}$ with certain k values are restricted, irrespective of those precoders' l values. If signaled as only a bitmap of l values, the device in some embodiments assumes that any beam precoders $v_{k,l}$ with certain l values are restricted, irrespective of those precoders' k values. If signaled as both a bitmap of k values and a bitmap of l values, the device in some embodiments assumes that only beam precoders $v_{k,l}$ with certain (k, l) value pairs as collectively defined by those bitmaps are restricted.

That said, restrictions specified in term of k and/or l values may in some sense be deemed as restrictions at a finer level of granularity than even the beam precoders themselves. Indeed, as noted above, each beam precoder $v_{k,l}$, is in some embodiments a Kronecker product of a vertical beamforming vector x_V with index k and a horizontal beamforming vector x_H with index l. Accordingly, signaling the restriction as k and/or l values effectively amounts to restricting (sub)components x_H or x_V.

Consider an example of these finer-granularity embodiments where codebook subset restriction is to be applied to beam precoders with l values of 3 or 4. If this configuration of codebook subset restriction would be signaled with a conventional bitmap, $N = N_H \cdot N_V = 64$ bits would be used. By contrast, the scheme in these finer-granularity embodiments consider restriction of entire precoder "rows", i.e all precoders that are formed from beam precoders with the same l-index is either turned on or off. To signal the codebook subset restriction in this example, therefore, the bitmap '00011000' of l values, consisting of $N_V = 8$ bits, may be sent. With this scheme, a large reduction of the number of bits required to signal the codebook subset restriction is seen. However, not all of the 2^N possible codebook subset restrictions may be signaled.

In a similar embodiment, the restriction is applied on the precoder "columns" k and the codebook subset restriction is signaled with a N_H bit long bitmap, indicating restrictions of entire precoder "columns".

In another embodiment an extra initial bit is inserted where '1' indicates that encoding is done as above "row wise", whereas a '0' indicates is done "column wise".

In yet another embodiment, the device 14 shall assume that a precoder W is restricted if both the vertical and the horizontal precoder in the Kronecker structure are restricted. If only one of the vertical and horizontal precoders are restricted, then the device 14 shall not assume that the resulting precoder after Kronecker operation is restricted.

Thus, one or more embodiments herein advantageously exploit a codebook's Kronecker structure to generate the signaling of Figure 5 in terms of indices k, l, and/or m. In some embodiments, for example, the signaling is generated to jointly restrict, e.g., with a single bit, a group of precoders that either (i) have the same value of index k; (ii) have the same value of index l; or (iii) have the same pair of values for indices (k, l).

In some embodiments, signaling that jointly restricts a group of precoders by restricting a certain component (e.g., beam precoder) that those precoders have in common is rank-agnostic. That is, the signaling jointly restricts the group of precoders regardless of the precoders' transmission rank (i.e., regardless of which rank-specific codebook they belong to). For example, embodiments that restrict a single beam precoder b_0 can be extended so that all precoders across all ranks that contain the restricted beam precoder b_0 are restricted. Hence, all precoders across all ranks that contain a certain beam precoder b_0 is a precoder group that can be restricted jointly. According to some embodiments, therefore, an advantage of signaling

CSR based on beam precoders is that one does not need to signal a separate CSR for precoders with different rank (precoders with different rank are restricted with the same CSR). This reduces signaling overhead.

Signaling that jointly restricts a group of precoders by restricting a certain component that those precoders have in common also proves effective for restricting precoders that transmit in whole or in part towards certain angular pointing directions. Indeed, according to some embodiments herein, the network node 10 jointly restricts a group of precoders that transmit at least in part towards a certain angular pointing direction, by restricting a certain component (e.g., beam precoder) which has that angular pointing direction. In this way, the network node 10 avoids transmitting energy in a certain direction, by signaling to the device 14 by means of CSR that the device 14 shall not compute feedback for that particular direction.

More specifically in this regard, when each precoder W is formed from multiple beam precoders, the precoder W in some sense has multiple angular pointing directions corresponding to the angular pointing directions of its constituent beam precoders (where each beam precoder has its own azimuth and zenith angular pointing direction for example). In another sense, though, the precoder W has an overall angular pointing direction that is a combination (e.g., average) of its beam precoders' respective directions. By restricting beam precoders that have certain angular pointing directions, embodiments herein effectively restrict precoders that transmit at least in part in those directions, and do so with reduced signaling overhead.

As an example, a set of rank-1 precoders with the same angular pointing direction but with different polarization properties, such as the whole set of rank-1 precoders

$$\begin{bmatrix} b_0 \\ e^{j\omega_0} b_0 \end{bmatrix}, \begin{bmatrix} b_0 \\ e^{j\omega_1} b_0 \end{bmatrix}, \begin{bmatrix} b_0 \\ e^{j\omega_2} b_0 \end{bmatrix},$$

may be restricted by restriction signaling of a single beam precoder b_0. That is, when a restriction is signaled for a certain beam precoder, the restriction applies implicitly to all polarization phases of the signaled beam. Hence, the group of rank-1 precoders exemplified above is associated with a single CSR bit and is thus jointly restricted. This reduces device complexity and CSR signaling overhead, since only the beam direction needs to be signaled.

In another example, the set of rank-1 precoders

$$\begin{bmatrix} b_0 \\ e^{j\omega_0} b_1 \end{bmatrix}, \begin{bmatrix} b_2 \\ e^{j\omega_1} b_0 \end{bmatrix}, \begin{bmatrix} b_0 \\ e^{j\omega_2} b_2 \end{bmatrix},$$

may be jointly restricted by restriction signaling of a single beam precoder b_0. Hence, the group of rank-1 precoders exemplified above is associated with a single CSR bit and is thus jointly restricted.

Restriction of precoders with certain angular pointing directions can also be accomplished by specifying restrictions in terms of certain k and/or l values. This is illustrated with reference to Figure 7, which illustrates the angular beam pointing directions of rank-1 precoders in a codebook according to one example. In this example, the network node has a 4x4 antenna array where no mechanical downtilt is used. The Kronecker codebook consists of 8 vertical and 8 horizontal precoders, i.e. $N_H = N_V = 8$. In this example, codebook subset restriction is applied to restrict beams with pointing directions in the zenith interval $[80°, 100°]$ (the interval is illustrated with dotted lines). That is, codebook subset restriction is applied in the angular interval $80° < \theta < 100°$, such that the precoders with indices l-index 3 and 4 are restricted. The restricted beams are illustrated with an 'o' while the unrestricted beams are illustrated with an 'x'. The beam index k in the horizontal codebook and l in the vertical codebook is written next to the beams as (k, l). To signal the codebook subset restriction in this example, therefore, the bitmap '00011000' of l values, consisting of $N_V = 8$ bits, may be sent. With this scheme, a large reduction of the number of bits required to signal the codebook subset restriction is seen.

In another embodiment, the device 14 shall assume that a precoder is restricted if both the vertical and horizontal precoder in the Kronecker structure are restricted. This allows to restrict a rectangular "window" of beam former pointing angles as seen from the network node 10.

This can also be accomplished by signaling the restriction as a "rectangle" of precoders defined by the index pairs (k_0, l_0) and (k_1, l_1). With this scheme, precoders with indices $k_0 < k < k_1$and $l_0 < l < l_1$ are restricted.

Component-based restriction of a precoder group is just one example of embodiments that provide for rank-agnostic CSR signalling. Other embodiments herein also provide for such rank-agnostic signaling. For example, some embodiments herein generate signaling to jointly indicate that a group of precoders which transmit in whole or in part in certain angular pointing direction(s) are restricted, by generating the signaling to (explicitly or implicitly) indicate those angular pointing direction(s). The signaling may for instance specify an angular area or interval that is restricted, in terms of one or more angular parameters. This restriction may concern the angular pointing direction of a precoder as a whole, or the angular pointing direction of any beam precoder forming the precoder.

In one embodiment, the angular area or interval may be represented by angular points (ϕ_0, θ_0) and (ϕ_1, θ_1), spanning a rectangle in the angular domain. Here, ϕ and θ are the azimuth and zenith angles with respect to the eNodeB respectivly. Multiple such rectangular areas may be signaled although the present embodiment focuses on the case of a single rectangular area for simplicity. The device 14 may then calculate the angular pointing directions of the precoders in the codebook and compare them to the restricted angular area to derive the codebook subset restriction. The device 14 may need some additional information regarding what to assume about the transmitter antenna array (which does not need to correspond to the actually used antenna array) to be able to calculate the pointing directions of the precoders.

Consider an exemplary embodiment where the (sub)-codebooks of the Kronecker codebook consist of DFT-precoders, i.e

The horizontal codebook can be expressed as

$$\mathbf{X}_H^k = \left[1 \ e^{j2\pi\frac{1k+\Delta_h}{M_h Q_h}} \ \cdots \ e^{j2\pi\frac{(M_h-1)k+\Delta_h}{M_h Q_h}}\right]^T$$ $,k = 0, \ldots, M_h Q_h - 1$, where Q_h is an integer horizontal oversampling factor and Δ_h can take on value in the interval 0 to 1 so as to "shift" the beam pattern (Δ_h =0.5 could be an interesting value for creating symmetry of beams with respect to the broadside of an array).

The vertical codebook can be expressed as $X_V^l = \left[1 \ e^{j2\pi\frac{1l+\Delta_v}{M_v Q_v}} \ \cdots \ e^{j2\pi\frac{(M_v-1)l+\Delta_v}{M_v Q_v}}\right]^T$, $l = 0, \ldots, M_v Q_v - 1$, where $Q_v$is an integer vertical oversampling factor and Δ_v is similarly defined as above.

The pointing direction of precoder (k, l) can be calculated by first calculating the pointing angle with respect to the broadside of the antenna array:

$$\tilde{\theta} = acos(\frac{k + \Delta - \frac{Q_v M_v}{2}}{d_V Q_v M_v})$$

$$\tilde{\phi} = asin(\frac{l + \Delta - \frac{Q_h M_h}{2}}{d_H Q_h M_h \, sin(\tilde{\theta})})$$

Where d_V and d_H is the vertical and horizontal antenna element spacing of the array, in wavelengths, respectively. The mechanical downtilt angle β is taken into account in order to calculate the actual beam pointing angles as:

$$\phi = \angle(cos(\tilde{\phi})\, sin(\tilde{\theta})\, cos(-\beta) - cos(\tilde{\theta})\, sin(-\beta) + j\, sin(\tilde{\theta})\, sin(\tilde{\theta}))$$

$$\theta = acos(cos(\tilde{\phi})\, sin(\tilde{\theta})\, sin(-\beta) + cos(-\beta)\, cos(\tilde{\theta}))$$

The device 14 needs to be signaled the additional information d_H, d_V and β to be able to calculate the beam pointing direction of the precoders in the codebook. It is assumed that the device 14 already knows the parameters Q_v, M_v, Q_h, M_h and Δ as part of the codebook structure.

The set of parameters $\phi_0, \theta_0, \phi_1, \theta_1, d_H, d_V, \beta$ thus parameterizes the codebook subset restriction in this embodiment. When signaling said parameters, several strategies may be used.

In one embodiment, each parameter is uniformly quantized with a number of bits, over a predefined interval. An example is given in the table below.

Parameters	Interval	Quantization bits
$\phi_0, \theta_0, \phi_1, \theta_1$	[0,180] [deg]	6
d_H, d_V	[0,2]	4
β	[-30,30] [deg]	6

In this embodiment, the number of bits required to signal the codebook subset restriction is 38. Note that this is independent of the codebook size.

In another embodiment, each parameter may take a value from a fixed set of possible values. Each possible value of the parameter is encoded with a different number of bits depending on e.g. the perceived likelihood of the parameter taking that value. For example, the horizontal array element spacing d_H may be encoded as follows

Value	0.5	0.8	0.65	1	4	2	0.75
Bits	1	01	0011	0010	0001	00001	00000

In this embodiment, the encoding of d_H was designed to take into account $d_H = 0.5$ is a common value for horizontal antenna element separation, thus encoding this value with a low number of bits. Other, less common, values are encoded with a larger number of bits. Note that the encoding of d_H in this embodiment constitutes a uniquely decodable code.

In another embodiment, some of the parameters are uniformly quantized with a number of bits over a predefined interval, while other parameters are encoded with a different number of bits as in the previous embodiment.

In some other embodiments, different sets of parameters relating to the restricted angular area may constitute the parameters that define the codebook subset restriction. In one such embodiment, only a zenith interval $\theta_0 \leq \theta < \theta_1$ is restricted, and thus, θ_0, θ_1 may be sent. In another such embodiment, the restriction is only an azimuth interval $\phi_0 \leq \phi < \phi_1$. In yet another such embodiment, the angle interval may be open-ended, i.e. $\phi < \phi_1$ constitutes the restriction.

In other embodiments, parameters relating to the antenna array such as d_H, d_V and Ψ are not a part of the codebook subset restriction parameters, instead they may be already known to the UE or the UE assumes a default value of said parameters and the eNodeB chooses restriction angles (ϕ_0, θ_0) and (ϕ_1, θ_1) in such a way that the intended precoders are restricted when the UE calculates the restriction based on the default values of said parameters, where the default values of said parameters may differ from the actual value of said parameters.

In other embodiments, more parameters may be included in the codebook subset restriction parameters. In one such embodiment, the roll angle γ of the antenna array may be included in the codebook subset restriction parameters.

In view of the above modifications and variations, one recognizes that there are many ways that the CSR signaling can jointly restrict precoders in a group. The signaling can be rank-agnostic or not. And the signaling can restrict a certain component that is common to the group or signal angular parameters associated with the group. The signaling can take the form of a bitmap for beam precoder indices, take the form of angular parameters, take the form of sub-codebook index pairs, take the form of a bitmap for indices of a single sub-codebook, etc. Irrespective of these particular variations, though, CSR signaling overhead is reduced based on correlation of the precoder restrictions or equivalently grouping of precoders. But the group-based joint restriction means that not all of the 2^N codebook subset restriction configurations are possible to convey to the device 14. Instead, only a subset of the possible configurations may be chosen.

Accordingly, at least some embodiments balance the loss in flexibility caused by joint restriction with the signaling overhead gains by such joint restriction by performing joint restriction with respect to only a portion of precoders in the codebook. That is, codebook subset restriction may be configured with full flexibility on a subset A of the precoders in the codebook (meaning that each of the precoders may be turned on or off individually), while only a few configurations may be chosen for the remaining set B of precoders. For example, the codebook subset restriction for the remaining set B of precoders may only be represented with one bit, turning all precoders in the set either on or off. This will reduce the CSR signaling overhead which is beneficial.

As an example in the context of beam precoders, the codebook may consist of two sets of precoders. One of the sets consist of precoders which may be equivalently expressed as a function of layer-specific beam precoders (as defined above) while the other set may consist of arbitrary precoders. In this embodiment, the first set of precoders may be configured with full flexibility while the other precoders in the codebook may be configured with limited flexibility.

This embodiment is just one example of grouping of the precoders in the codebook where precoders belonging to set A is individually represented by one bit while precoders in set B are all jointly restricted with a single bit. This embodiment can be further extended by having multiple sets B as B_1,B_2,... B_N where each of the set B_n, n=1,...,N contain at least two precoders each and is associated with one CSR bit. In Figure 8 an example is shown where Precoder 1 to 14 are each represented by an individual bit (Set A), while all precoders in group B1 are represented by a single CSR bit, e.g. the bit for precoder 15.

The defined groups may also be overlapping, so that a given precoder exists in multiple groups. If this is the case, then priority or combining rules needs to be defined, so that the device 14 understands how to interpret the case when one precoder is restricted by the signaling of one group but not from another group it belong to.

In a further detailed embodiment, therefore, the groups B_n in Figure 8 may be overlapping and rules are specified in standard text on how the device 14 shall interpret CSR signaling. For instance, assume two groups B_1 and B_2 each represented by one bit and that one precoder belongs to both groups. One rule may be that if a precoder is restricted in any of the groups it belongs, then the precoder should be assumed to be restricted. Another alternative is that the precoder must be restricted in both groups for the precoder to be assumed to be restricted.

In some embodiments in this disclosure, codebook subset restriction is discussed using the terminology *precoders* and *codebooks*. It may be assumed that beam specific restriction is used in said embodiments, and that the terminology may be interchanged to *beam precoders* and *set of beam precoders*, depending on the granularity being discussed.

Note that although terminology from 3GPP LTE has been used in this disclosure to exemplify embodiments herein, this should not be seen as limiting the scope of the embodiments to only the aforementioned system. Other wireless systems, including WCDMA, WiMax, UMB and GSM, may also benefit from exploiting the ideas covered within this disclosure.

Also note that terminology such as eNodeB and UE should be considering non-limiting and does in particular not imply a certain hierarchical relation between the two; in general "eNodeB" could be considered as device 1 and "UE" device 2, and these two devices communicate with each other over some radio channel. Herein, we also focus on wireless transmissions in the downlink, but embodiments herein are equally applicable in the uplink.

Embodiments herein also include methods in a wireless communication device 14 corresponding to the methods described above in a network node 10. These methods receive and decode the signaling that the network node 10 generates according to any of the embodiments above.

According to one embodiment shown in Figure 9, for example, a method is implemented by a wireless communication device 14 (e.g., a UE) for decoding signaling from a network node 10 indicating which precoders in a codebook are restricted from being used. The method includes receiving the signaling (Block 300). The method also includes, for each of one or more groups of precoders in the codebook, decoding the signaling to identify which of different possible configurations is actually signaled for that group. Different possible configurations in this regard restrict different subgroups of precoders in the group from being used. This decoding proceeds on a group-by-group basis, starting with a first group (Block 310). Specifically, the decoding entails identifying one or more reference configurations for the first group, the bit pattern identified for signaling each reference configuration, and the length of that bit pattern (Block 320). These reference configuration(s) may be predefined at the device 14, or may be signaled from the network node 10. Regardless, decoding then entails detecting the actual configuration signaled for the group, by detecting a bit pattern in the received signaling whose length depends on (i) whether the actual configuration matches one of the one or more reference configurations; and/or (ii) which reference configuration the actual configuration matches (Block 330).

Such may entail, for example, determining the length *B* of the bit pattern defined for signaling a particular reference configuration, and checking whether a *B*-length string of the next bits in the signaling corresponds to the bit pattern defined for signaling that reference configuration. This determination and checking may be performed for each of the one or more reference configurations, after which (if no reference configurations are identified as being signaled) a default-length string of the next bits in the signaling is decoded for detecting non-reference configurations.

Regardless of the particular implementation of the decoding process (Blocks 320-330), the decoding is repeated for each of the one or more groups of precoders in the codebook (Blocks 340, 350).

Those skilled in the art will appreciate that the device-side embodiments include decoding of any of the network-side embodiments illustrated with reference to Figure 3, including for instance the "similar rows embodiments" and the "similar columns embodiment."

According to one or more other embodiments shown in Figure 10, a method is implemented by a wireless communication device 14 (e.g., a UE) for decoding signaling from a network node 10 indicating which precoders in a codebook are restricted from being used (e.g., which Kronecker product precoders are restricted). As shown, the method includes receiving the signaling from a network node 10 (e.g., a base station) (Block 400). The method also includes decoding the signaling as jointly restricting precoders in each of one or more groups of precoders (Block 410). In at least some embodiments, such decoding involves decoding the signaling (i) as being rank-agnostic so as to restrict precoders irrespective of their transmission rank; and/or (ii) as jointly restricting a group of precoders by restricting a certain component that those precoders have in common.

Those skilled in the art will appreciate that the device-side embodiments include decoding of any of the network-side embodiments illustrated with reference to Figure 5. So, for example, the device 14 in some embodiments decodes the signaling as jointly restricting a group of precoders that have a certain beam precoder in common, by restricting that beam precoder. And one or more device-side embodiments likewise advantageously exploit a codebook's Kronecker structure to decode the signaling of Figure 10 in terms of indices k, l, and/or m. In some embodiments, for example, the signaling is decoding as jointly restricting, e.g., with a single bit, a group of precoders that either (i) have the same value of index k; (ii) have the same value of index l; or (iii) have the same pair of values for indices (k, l).

With the above modifications and variations in mind, Figure 11 illustrates additional details of the network node 500 (corresponding to network node 10) according to one or more embodiments. The network node 500 is configured, e.g., via functional means or units 540-570, to implement the processing in Figure 2 for signaling to a wireless communication device 14 which precoders in a codebook are restricted from being used. The network node 500 in some embodiments for example includes a reference configuration identifying means or unit 540 for identifying one or more reference configurations for each of one or more groups of precoders. The network node 500 in such case further includes an actual configuration identifying means or unit 550 for identifying an actual configuration for each of the one or more groups. The network node 500 also includes a signal generating means or unit 560 for generating signaling to indicate the actual configuration for each of the one or more groups, by generating the signaling as a bit pattern whose length depends on (i) whether the actual configuration matches one of the one or more reference configurations; and/or (ii) which reference configuration the actual configuration matches. The network node 500 finally includes a sending means or unit 570 for sending the generated signaling to the wireless communication device.

In at least some embodiments, the network node 500 comprises one or more processing circuits 510 configured to implement this processing, such as by implementing functional means or units 540-570. In one embodiment, for example, the node's processing circuit(s) 510 implement functional means or units 540-570 as respective circuits. The circuits in this regard may comprise circuits dedicated to performing certain functional processing and/or one or more microprocessors in conjunction with memory 520. In embodiments that employ memory 520, which may comprise one or several types of memory such as read-only memory (ROM), random-access memory, cache memory, flash memory devices, optical storage devices, etc., the memory stores program code that, when executed by the one or more for carrying out one or more microprocessors, carries out the techniques described herein.

In one or more embodiments, the network node 500 also comprises one or more communication interfaces 530. The one or more communication interfaces 530 include various components (not shown) for sending and receiving data and control signals. More particularly, the interface(s) 530 include a transmitter that is configured to use known signal processing techniques, typically according to one or more standards, and is configured to condition a signal for transmission (e.g., over the air via one or more antennas). Similarly, the interface(s) 530 include a receiver that is configured to convert signals received (e.g., via the antenna(s)) into digital samples for processing by the one or more processing circuits 510.

Figure 12 illustrates additional details of the network node 600 according to one or more embodiments. The network node 600 is configured, e.g., via functional means or units 640-650, to implement the processing in Figure 5 for signaling to a wireless communication device which precoders in a codebook are restricted from being used. The network node 600 in some embodiments for example includes a generating means or unit 640 for generating codebook subset restriction signaling that, for each of one or more groups of precoders, jointly restricts the precoders in the group, e.g., with a single signaling bit. The network node 600 also includes a sending means or unit 650 for sending the generated signaling to the wireless communication device.

In at least some embodiments, the network node 600 comprises one or more processing circuits 610 configured to implement this processing, such as by implementing functional means or units 640-650. In one embodiment, for example, the node's processing circuit(s) 610 implement functional means or units 640-650 as respective circuits (similarly to that described above, e.g., in conjunction with memory 620). In one or more embodiments, the network node 600 also comprises one or more communication interfaces 630.

Figure 13 illustrates additional details of the wireless communication device 700 (corresponding to wireless communication device 14) according to one or more embodiments. The device 700 is configured, e.g., via functional means or units 740-760, to implement the processing in Figure 9 for decoding signaling from a network node indicating which precoders in a codebook are restricted from being used. The device 700 in some embodiments for example includes a receiving means or unit 740 for receiving the signaling from the network node. The device 700 further includes an identifying means or unit 750 configured, for each of one or more groups of precoders, to identify one or more reference configurations for the group, the bit pattern identified for signaling each reference configuration, and the length of that bit pattern. The device 700 finally includes a detecting means or unit 760 configured to detect the actual configuration signaled for the group, by detecting a bit pattern in the received signaling whose length depends on (i) whether the actual configuration matches one of the one or more reference configurations; and/or (ii) which reference configuration the actual configuration matches.

In at least some embodiments, the device 700 comprises one or more processing circuits 710 configured to implement this processing, such as by implementing functional means or units 740-760. In one embodiment, for example, the device's processing circuit(s) 710 implement functional means or units 740-760 as respective circuits. The circuits in this regard may comprise circuits dedicated to performing certain functional processing and/or one or more microprocessors in conjunction with memory 720. In embodiments that employ memory 720, which may comprise one or several types of memory such as read-only memory (ROM), random-access memory, cache memory, flash memory devices, optical storage devices, etc., the memory stores program code that, when executed by the one or more for carrying out one or more microprocessors, carries out the techniques described herein.

In one or more embodiments, the device 700 also comprises one or more communication interfaces 730. The one or more communication interfaces 730 include various components (not shown) for sending and receiving data and control signals. More particularly, the interface(s) 730 include a transmitter that is configured to use known signal processing techniques, typically according to one or more standards, and is configured to condition a signal for transmission (e.g., over the air via one or more antennas). Similarly, the interface(s) 730 include a receiver that is configured to convert signals received (e.g., via the antenna(s)) into digital samples for processing by the one or more processing circuits 710.

Figure 14 illustrates additional details of the device 800 according to one or more other embodiments. The device 800 is configured, e.g., via functional means or units 840-850, to implement the processing in Figure 10 for decoding signaling from a network node indicating which precoders in a codebook are restricted from being used. The device 800 in some embodiments for example includes a receiving means or unit 840 for receiving the signaling from the network node. The device 800 further includes a decoding means or unit 850 for decoding the signaling as jointly restricting precoders in each of one or more groups of precoders.

In at least some embodiments, the device 800 comprises one or more processing circuits 810 configured to implement this processing, such as by implementing functional means or units 840-850. In one embodiment, for example, the device's processing circuit(s) 810 implement functional means or units 840-850 as respective circuits (similarly to that described above, e.g., in conjunction with memory 820). In one or more embodiments, the device 800 also comprises one or more communication interfaces 830.

Those skilled in the art will also appreciate that embodiments herein further include corresponding computer programs.

A computer program comprises instructions which, when executed on at least one processor of the network node or the wireless communication device, cause node or device to carry out any of the respective processing described above. Embodiments further include a carrier containing such a computer program. This carrier may comprise one of an electronic signal, optical signal, radio signal, or computer readable storage medium.

A computer program in this regard may comprise one or more code modules corresponding to the means or units described above.

General Embodiments

In a first embodiment, a UE is able to receive messages in order to turn individual codewords on/off. The following holds for the set of possible messages:

At least one of these messages, which correspond to a certain configuration out of the 2^N possible configurations, is represented by less than N bits.

The message will contain information to define on/off for each individual codeword in the entire codebook.

Each message is uniquely decodable to the UE and will correspond to one of the 2^N possible configurations.

In a second embodiment, the UE of the first embodiment is configured such that codebook subset restriction is done on beam precoders.

In a third embodiment, the UE of the first embodiment is configured such that codebook subset restriction is configured with full flexibility for a subset of precoders in the codebook, while codebook subset restriction is configured with a limited flexibility for other precoders in the codebook.

In a fourth embodiment, the UE of the third embodiment is configured such that the set of precoders for which codebook subset restriction is configured with full flexibility is the set of precoders that may be equivalently expressed as a function of layer-specific beam precoders.

In a fifth embodiment, the UE of the first embodiment is configured such that N = N_H· N_V from the Kronecker structure.

In a sixth embodiment, the UE of any of the first through the fifth embodiments is configured such that the information used to design the set of messages consists of information about angular intervals which are likely to be restricted.

In a seventh embodiment, the UE of the first embodiment is configured such that only a subset of the 2^N possible configurations may be configured.

In an eighth embodiment, the UE of the first embodiment is configured such that at least one of the messages, which corresponds to a certain configuration out of the 2^N possible configurations, is represented more than N bits.

In a ninth embodiment, the UE of the first embodiment is configured such that the set of messages are designed using information about the likelihood of certain configurations being chosen.

In a tenth embodiment, the UE of the first embodiment is configured such that the information about the likelihood of certain configurations being chosen is only an implicit assumption of the likelihoods.

In an eleventh embodiment, the UE of the first embodiment is configured such that a set of angles specifies the configuration.

CLAIMS

What is claimed is:

1. A method implemented by a network node (10) for signaling to a wireless communication device (14) which precoders in a codebook are restricted from being used, the method characterized by:

generating (210) codebook subset restriction signaling that, for each of one or more groups of precoders, jointly restricts the precoders in the group by restricting a certain component that the precoders in the group have in common; and

sending (220) the generated signaling from the network node (10) to the wireless communication device (14).

2. A method implemented by a wireless communication device (14) for decoding signaling from a network node (10) indicating which precoders in a codebook are restricted from being used, the method characterized by:

receiving (400) codebook subset restriction signaling that, for each of one or more groups of precoders, jointly restricts the precoders in the group by restricting a certain component that the precoders in the group have in common; and

decoding (410) the received signaling as jointly restricting precoders in each of the one or more groups of precoders.

3. The method of any of claims 1-2, wherein the codebook subset restriction signaling is rank-agnostic signaling that jointly restricts the precoders in a group without regard to the precoders' transmission rank.

4. The method of any of claims 1-3, wherein the certain component comprises a beam precoder.

5. The method of any of claims 1-4, wherein a precoder comprising one or more beam precoders is restricted if at least one of its one or more beam precoders is restricted.

6. The method of any of claims 4-5, wherein a beam precoder is a Kronecker product of different beamforming vectors associated with different dimensions of a multi-dimensional antenna array.

7. The method of claim 6, wherein the different beamforming vectors comprise Discrete Fourier Transform (DFT) vectors.

8. The method of any of claims 4-7, wherein a beam precoder is a beamforming vector used to transmit on a particular layer of a multi-layer transmission, wherein different scaled versions of that beamforming vector are transmitted on different polarizations;

9. The method of any of claims 4-7, wherein a beam precoder is a beamforming vector used to transmit on:

multiple different layers of a multi-layer transmission;

multiple different layers of a multi-layer transmission, wherein the layers are sent on orthogonal polarizations; or

a particular layer and on a particular polarization.

10. The method of any of claims 1-9, wherein the codebook subset restriction signaling comprises a bitmap, with different bits in the bitmap respectively dedicated to indicating whether or not different beam precoders are restricted from being used.

11. The method of any of claims 1-9, wherein a beam precoder is a Kronecker product of first and second beamforming vectors with first and second indices, wherein the first and second beamforming vectors are associated with different dimensions of a multi-dimensional antenna array, and wherein the codebook subset restriction signaling jointly restricts the precoders in a group of precoders that have the same pair of values for the first and second indices.

12. The method of any of claims 1-3, wherein each precoder comprises one or more beam precoders, wherein each beam precoder comprises multiple different components corresponding to different dimensions of a multi-dimensional antenna array, and wherein said certain component comprises a component of a beam precoder.

13. The method of any of claims 1-12, wherein the codebook subset restriction signaling jointly restricts the precoders in a group of precoders that transmit at least in part towards a certain angular pointing direction, by restricting a certain component which has that angular pointing direction.

14. A method implemented by a network node (10) for signaling to a wireless communication device (14) which precoders in a codebook are restricted from being used, the method characterized by:

for each of one or more groups of precoders in the codebook:

identifying (110) one or more reference configurations for the group, wherein each reference configuration is one of different possible configurations that restrict different subgroups of precoders in the group from being used;

identifying (120), from the different possible configurations for the group, an actual configuration to be signaled for the group; and

generating (130) signaling to indicate the actual configuration for the group, by generating the signaling as a bit pattern whose length depends on (i) whether the actual configuration matches one of the one or more reference configurations and/or (ii) which reference configuration the actual configuration matches; and

sending (160) the generated signaling to the wireless communication device (14).

15. A method implemented by a wireless communication device (14) for decoding signaling from a network node (10) indicating which precoders in a codebook are restricted from being used, the method characterized by:

receiving (300) signaling from the network node (10),

for each of one or more groups of precoders in the codebook:

identifying (320) one or more reference configurations for the group, wherein each reference configuration is one of different possible configurations that restrict different subgroups of precoders in the group from being used;

identifying (320) a bit pattern defined for signaling each reference configuration, and a length of that bit pattern; and

detecting (330) an actual configuration signaled for the group, by detecting in the signaling a bit pattern whose length depends on (i) whether the actual configuration matches one of the one or more reference configurations and/or (ii) which reference configuration the actual configuration matches.

16. The method of any of claims 14-15, wherein the signaling is a short bit pattern when the actual configuration matches any one of the one or more reference configurations and is a long bit pattern when the actual configuration does not match any of the one or more reference configurations, wherein a long bit pattern has more bits than a short bit pattern.

17. The method of claim 16, wherein the one or more reference configurations for at least one of the one or more groups comprise a single reference configuration, and wherein different long bit patterns are respectively defined for signaling different configurations other than the single reference configuration.

18. The method of any of claims 16-17, wherein a long bit pattern defined for signaling the actual configuration for the group comprises:

a non-reference bit pattern defined for signaling that the actual configuration does not match a reference configuration for the group; and

a bitmap comprising different bits respectively dedicated to indicating whether different precoders in the group are restricted from being used.

19. The method of any of claims 14-15, wherein the one or more reference configurations for at least one of the one or more groups comprise multiple reference configurations, and wherein, when the actual configuration matches a particular one of the multiple reference configurations, the signaling is a bit pattern whose length is shorter than that of a bit pattern generated when the actual configuration matches a different one of the multiple reference configurations.

20. The method of any of claims 14-19, wherein the one or more reference configurations for a group each have an actual or assumed higher probability of being signaled than any other possible configuration that is not one of the one or more reference configurations.

21. The method of any of claims 14-19, wherein the method is performed for multiple different groups that respectively include different portions of the precoders in the codebook, wherein the signaling indicates the actual configurations for the groups in a defined order, wherein the one or more reference configurations for each group comprises a single reference configuration, and wherein the single reference configuration for any given group is the actual configuration, if any, signaled immediately before that of the given group.

22. The method of any of claims 14-21, wherein the codebook is a Kronecker codebook defined for a multi-dimensional antenna array and comprises different precoders indexed by different possible values of a single index parameter, wherein the different possible values of the single index parameter are divided into different clusters of consecutively ordered values, and wherein precoders in different ones of the one or more groups are respectively indexed by the different clusters of consecutively ordered values.

23. The method of any of claims 14-21, wherein the codebook is a Kronecker codebook defined for a multi-dimensional antenna array and comprises different precoders indexed by different pairs of possible values for a first-dimension index parameter and a second-dimension index parameter, and wherein precoders in each of the one or more groups are indexed by pairs that have the same value for either the first-dimension index parameter or the second-dimension index parameter.

24. A network node (10, 600) for signaling to a wireless communication device (14, 800) which precoders in a codebook are restricted from being used, the network node (10, 600) configured to:

generate codebook subset restriction signaling that, for each of one or more groups of precoders, jointly restricts the precoders in the group by restricting a certain component that the precoders in the group have in common; and

send the generated signaling from the network node (10, 600) to the wireless communication device (14, 800).

25. The network node of claim 24, configured to perform the method of any of claims 3-13.

26. A network node (10, 600) for signaling to a wireless communication device (14, 800) which precoders in a codebook are restricted from being used, the network node (10, 600) characterized by:

a generating module (640) for generating codebook subset restriction signaling that, for each of one or more groups of precoders, jointly restricts the precoders in the group by restricting a certain component that the precoders in the group have in common; and

a sending module (650) for sending the generated signaling from the network node (10, 600) to the wireless communication device (14, 800).

27. A wireless communication device (14, 800) for decoding signaling from a network node (10, 600) indicating which precoders in a codebook are restricted from being used, the wireless communication device (14, 800) configured to:

receive codebook subset restriction signaling that, for each of one or more groups of precoders, jointly restricts the precoders in the group by restricting a certain component that the precoders in the group have in common; and

decode the received signaling as jointly restricting precoders in each of the one or more groups of precoders.

28. The wireless communication device of claim 27, configured to perform the method of any of claims 3-13.

29. A wireless communication device (14, 800) for decoding signaling from a network node (10, 600) indicating which precoders in a codebook are restricted from being used, the wireless communication device (14, 800) characterized by:

a receiving module (840) for receiving codebook subset restriction signaling that, for each of one or more groups of precoders, jointly restricts the precoders in the group by restricting a certain component that the precoders in the group have in common; and

a decoding module (850) for decoding the received signaling as jointly restricting precoders in each of the one or more groups of precoders.

30. A network node (10, 500) for signaling to a wireless communication device which precoders in a codebook are restricted from being used, the network node (10, 500) configured to:

for each of one or more groups of precoders in the codebook:

identify one or more reference configurations for the group, wherein each reference configuration is one of different possible configurations that restrict different subgroups of precoders in the group from being used;

identify, from the different possible configurations for the group, an actual configuration to be signaled for the group; and

generate signaling to indicate the actual configuration for the group, by generating the signaling as a bit pattern whose length depends on (i) whether the actual configuration matches one of the one or more reference configurations and/or (ii) which reference configuration the actual configuration matches; and

send the generated signaling to the wireless communication device.

31. The network node of claim 30, configured to perform the method of any of claims 16-23.

32. A network node (10, 500) for signaling to a wireless communication device (14, 700) which precoders in a codebook are restricted from being used, the network node (10, 500) characterized by:

for each of one or more groups of precoders in the codebook:

a reference configuration identifying module (540) for identifying one or more reference configurations for the group, wherein each reference configuration is one of different possible configurations that restrict different subgroups of precoders in the group from being used;

an actual configuration identifying module (550) for identifying, from the different possible configurations for the group, an actual configuration to be signaled for the group; and

a generating module (560) for generating signaling to indicate the actual configuration for the group, by generating the signaling as a bit pattern whose length depends on (i) whether the actual configuration matches one of the one or more reference configurations and/or (ii) which reference configuration the actual configuration matches; and

a sending module (570) for sending the generated signaling to the wireless communication device (14, 700).

33. The network node of claim 32, configured to perform the method of any of claims 16-23.

34. A wireless communication device (14, 700) for decoding signaling from a network node (10, 500) indicating which precoders in a codebook are restricted from being used, the wireless communication device (14, 700) configured to:

receive signaling from the network node (10, 500).

for each of one or more groups of precoders in the codebook:

identify one or more reference configurations for the group, wherein each reference configuration is one of different possible configurations that restrict different subgroups of precoders in the group from being used;

identify a bit pattern defined for signaling each reference configuration, and a length of that bit pattern; and

detect an actual configuration signaled for the group, by detecting in the signaling a bit pattern whose length depends on (i) whether the actual configuration matches one of the one or more reference configurations and/or (ii) which reference configuration the actual configuration matches.

35. The wireless communication device of claim 34, configured to perform the method of any of claims 16-23.

36. A wireless communication device (14, 700) for decoding signaling from a network node (10, 500) indicating which precoders in a codebook are restricted from being used, the wireless communication device characterized by:

a receiving module (740) for receiving signaling from the network node (10, 500).

for each of one or more groups of precoders in the codebook:

an identifying module (750) for identifying one or more reference configurations for the group, wherein each reference configuration is one of different possible configurations that restrict different subgroups of precoders in the group from being used; and for identifying a bit pattern defined for signaling each reference configuration, and a length of that bit pattern; and

a detecting module (760) for detecting an actual configuration signaled for the group, by detecting in the signaling a bit pattern whose length depends on

(i) whether the actual configuration matches one of the one or more reference configurations and/or (ii) which reference configuration the actual configuration matches.

37. A computer program comprising instructions which, when executed by at least one processor of a node (10, 14), causes the node (10, 14) to carry out the method of any of embodiments 1-23.

38. A carrier containing the computer program of embodiment 37, wherein the carrier is one of an electronic signal, optical signal, radio signal, or computer readable storage medium.

ABSTRACT

A network node (10) signals to a wireless communication device (14) which precoders in a codebook are restricted from being used. The network node (10) in this regard generates codebook subset restriction signaling that, for each of one or more groups of precoders, jointly restricts the precoders in the group by restricting a certain component (e.g., a certain beam precoder) that the precoders in the group have in common. This signaling may be for instance rank-agnostic signaling that jointly restricts the precoders in a group without regard to the precoders' transmission rank. Regardless, the network node (10) sends the generated signaling to the wireless communication device (14).

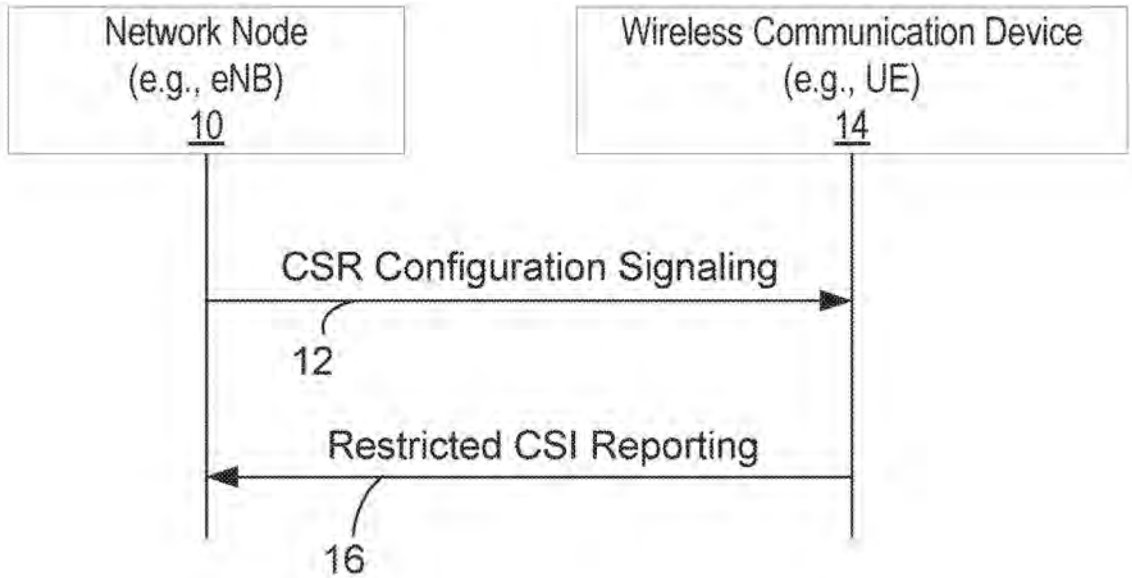

Network Node
(e.g., eNB)
10
Wireless Communication Device
(e.g., UE)
14
CSR Configuration Signaling
12
Restricted CSI Reporting
16

Figure 1

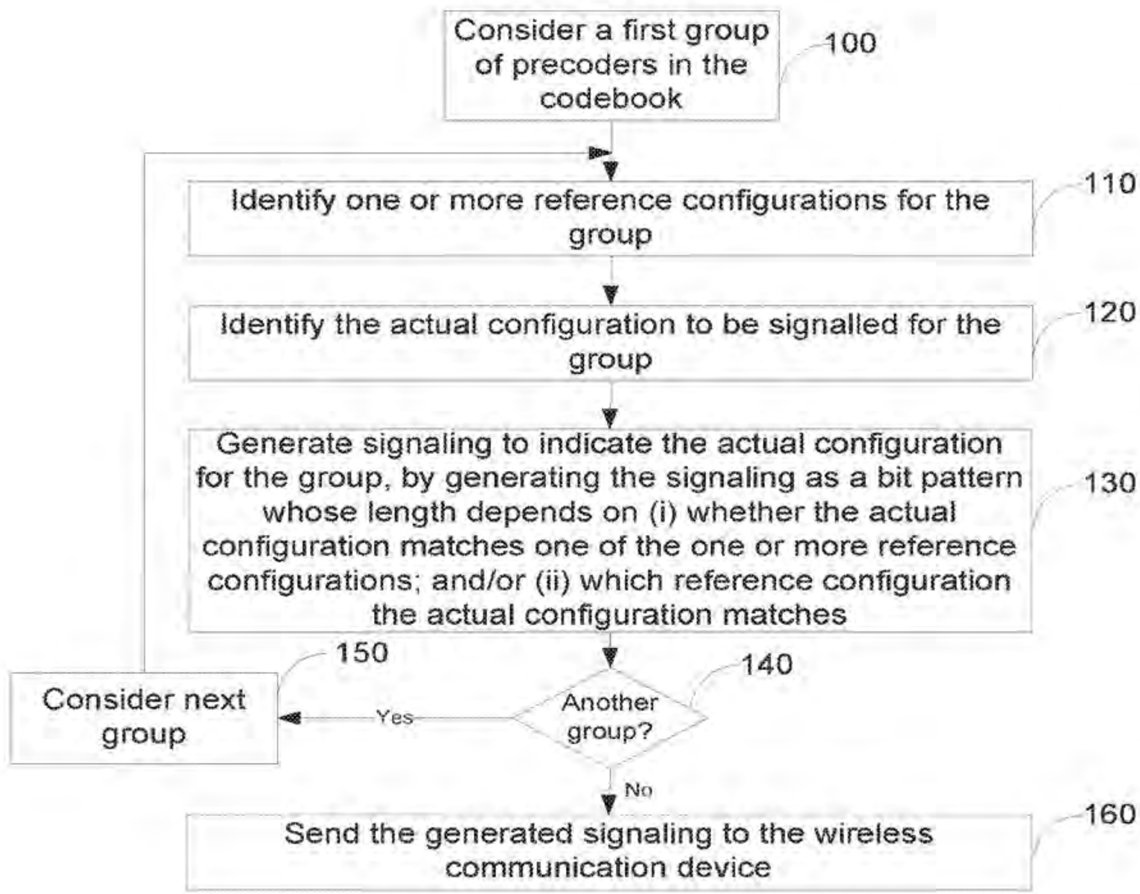

Consider a first group of precoders in the codebook
100
Identify one or more reference configurations for the group
110
Identify the actual configuration to be signalled for the group
120
Generate signaling to indicate the actual configuration for the group, by generating the signaling as a bit pattern whose length depends on (i) whether the actual configuration matches one of the one or more reference configurations; and/or (ii) which reference configuration the actual configuration matches
130
150
Consider next group
Yes
Another group?
140
No
Send the generated signaling to the wireless communication device
160

Figure 2

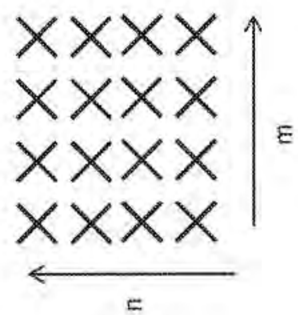


Figure 3

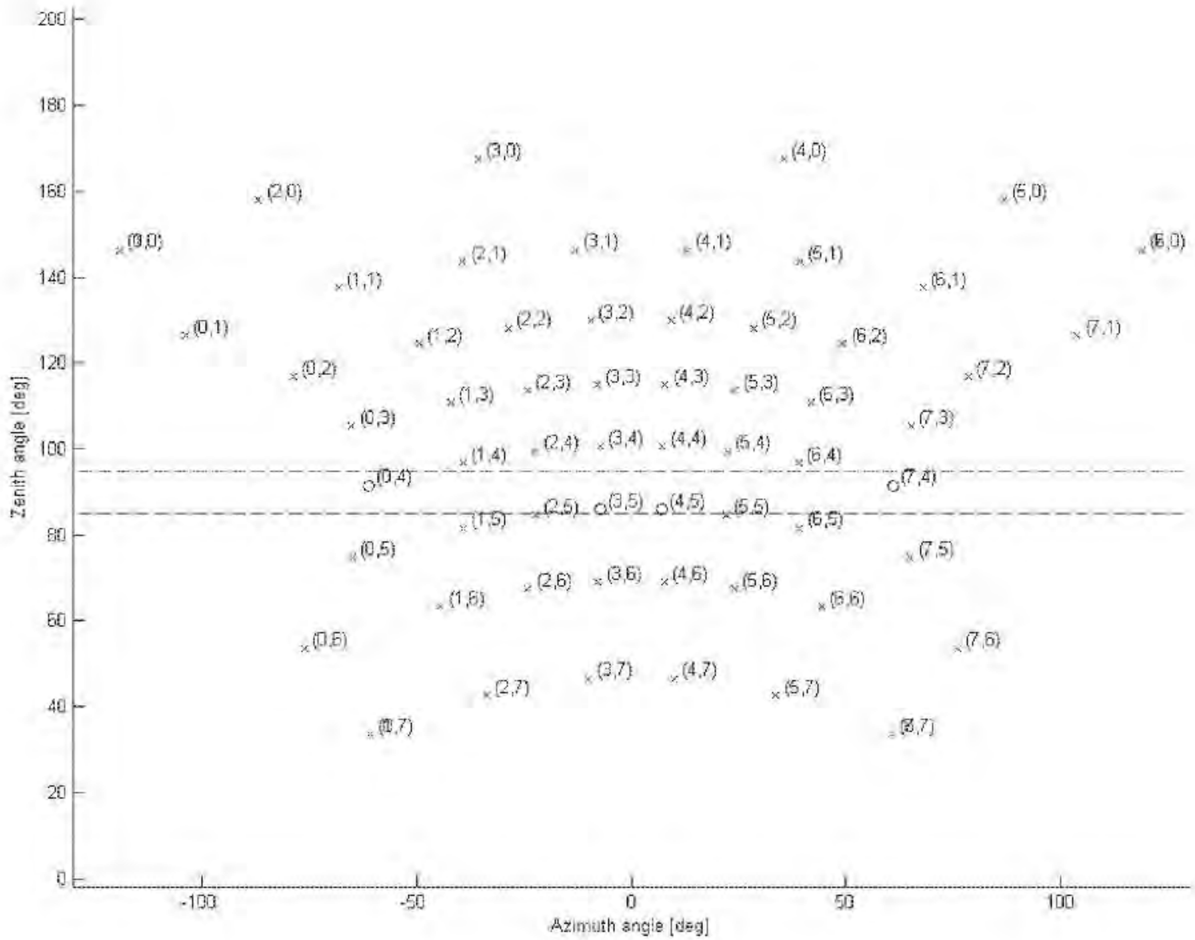


FIGURE 4

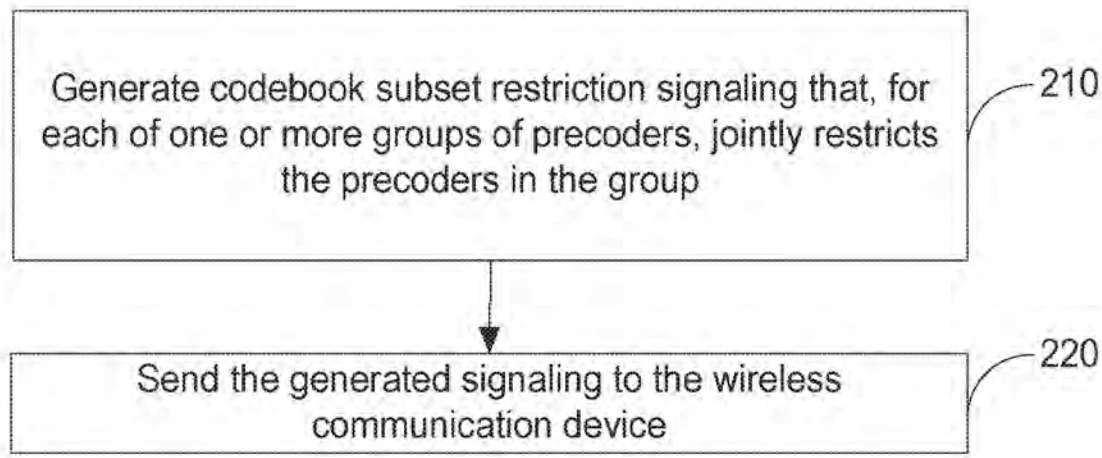

Generate codebook subset restriction signaling that, for each of one or more groups of precoders, jointly restricts the precoders in the group
210
Send the generated signaling to the wireless communication device
220

Figure 5

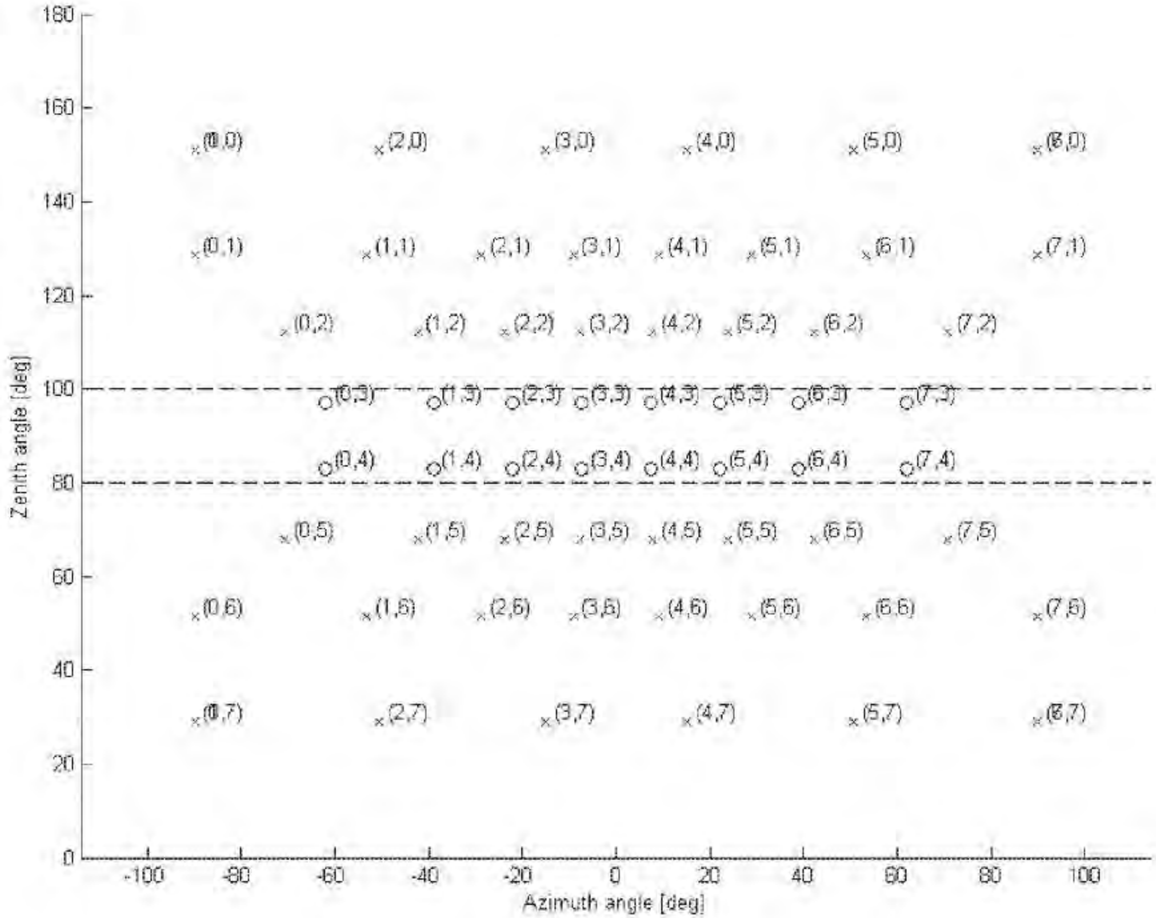
$$\varphi_n = e^{j\pi n/2}$$

$$v_m = \begin{bmatrix} 1 & e^{j2\pi m/32} & e^{j4\pi m/32} & e^{j6\pi m/32} \end{bmatrix}^T$$

Codebook for 2-layer CSI reporting using antenna ports 15 to 22

i_1	i_2			
	0	**1**	**2**	**3**
0 – 15	$W^{(2)}_{2i_1,2i_1,0}$	$W^{(2)}_{2i_1,2i_1,1}$	$W^{(2)}_{2i_1+1,2i_1+1,0}$	$W^{(2)}_{2i_1+1,2i_1+1,1}$
i_1	i_2			
	4	**5**	**6**	**7**
0 – 15	$W^{(2)}_{2i_1+2,2i_1+2,0}$	$W^{(2)}_{2i_1+2,2i_1+2,1}$	$W^{(2)}_{2i_1+3,2i_1+3,0}$	$W^{(2)}_{2i_1+3,2i_1+3,1}$
i_1	i_2			
	8	**9**	**10**	**11**
0 – 15	$W^{(2)}_{2i_1,2i_1+1,0}$	$W^{(2)}_{2i_1,2i_1+1,1}$	$W^{(2)}_{2i_1+1,2i_1+2,0}$	$W^{(2)}_{2i_1+1,2i_1+2,1}$
i_1	i_2			
	12	**13**	**14**	**15**
0 – 15	$W^{(2)}_{2i_1,2i_1+3,0}$	$W^{(2)}_{2i_1,2i_1+3,1}$	$W^{(2)}_{2i_1+1,2i_1+3,0}$	$W^{(2)}_{2i_1+1,2i_1+3,1}$
where $W^{(2)}_{m,m',n} = \frac{1}{4}\begin{bmatrix} v_m & v_{m'} \\ \varphi_n v_m & -\varphi_n v_{m'} \end{bmatrix}$				

Figure 6



Zenith angle [deg]
Azimuth angle [deg]
180
160
140
120
100
80
60
40
20
0
-100
-80
-60
-40
-20
0
20
40
60
80
100
(0,0) (2,0) (3,0) (4,0) (5,0) (6,0)
(0,1) (1,1) (2,1) (3,1) (4,1) (5,1) (6,1) (7,1)
(0,2) (1,2) (2,2) (3,2) (4,2) (5,2) (6,2) (7,2)
(0,3) (1,3) (2,3) (3,3) (4,3) (5,3) (6,3) (7,3)
(0,4) (1,4) (2,4) (3,4) (4,4) (5,4) (6,4) (7,4)
(0,5) (1,5) (2,5) (3,5) (4,5) (5,5) (6,5) (7,5)
(0,6) (1,6) (2,6) (3,6) (4,6) (5,6) (6,6) (7,6)
(0,7) (2,7) (3,7) (4,7) (5,7) (6,7)

Figure 7

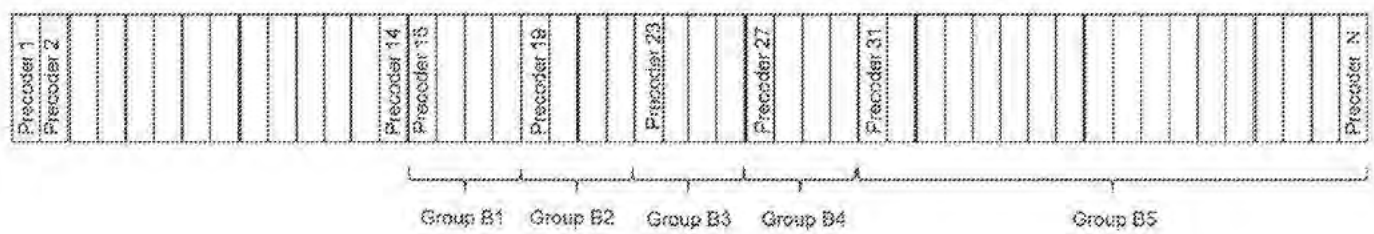

Precoder 1
Precoder 2
Precoder 14
Precoder 15
Precoder 19
Precoder 23
Precoder 27
Precoder 31
Precoder N
Group B1
Group B2
Group B3
Group B4
Group B5

Figure 8

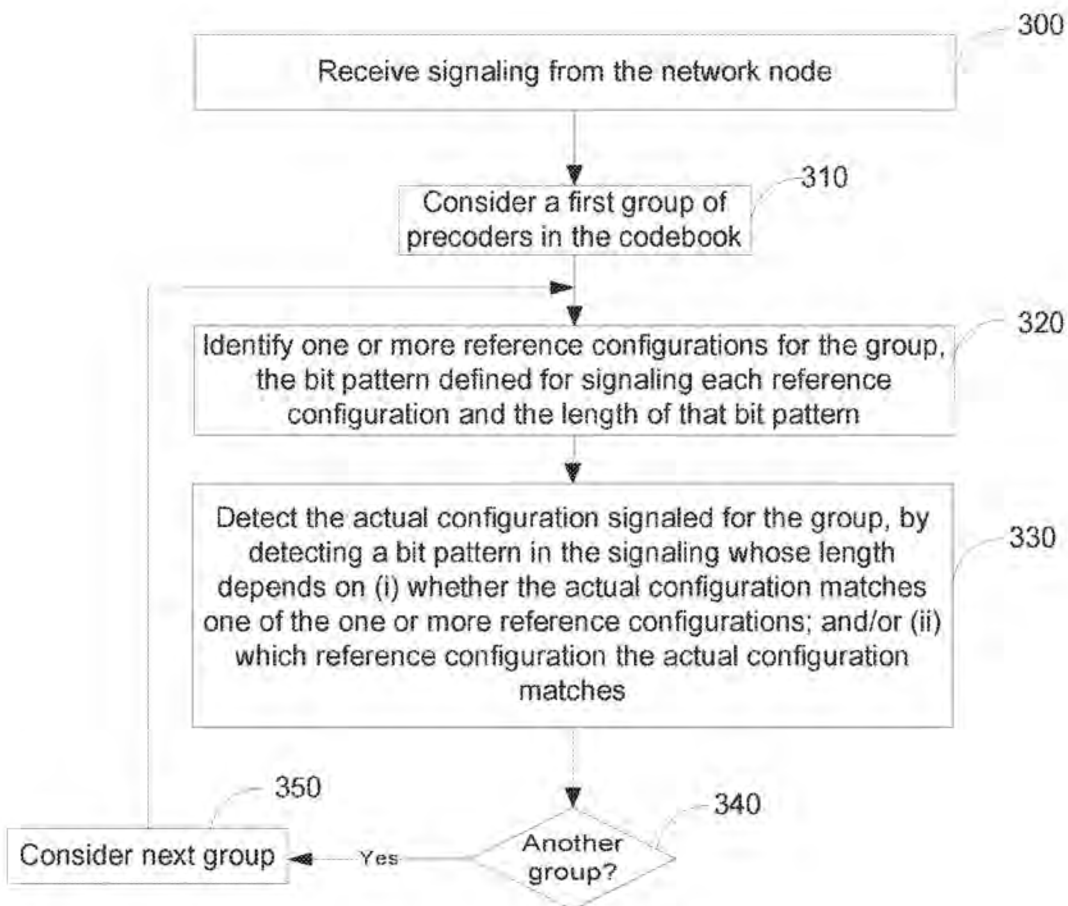

300
Receive signaling from the network node
310
Consider a first group of precoders in the codebook
320
Identify one or more reference configurations for the group, the bit pattern defined for signaling each reference configuration and the length of that bit pattern
330
Detect the actual configuration signaled for the group, by detecting a bit pattern in the signaling whose length depends on (i) whether the actual configuration matches one of the one or more reference configurations; and/or (ii) which reference configuration the actual configuration matches
350
Consider next group
Yes
340
Another group?

Figure 9

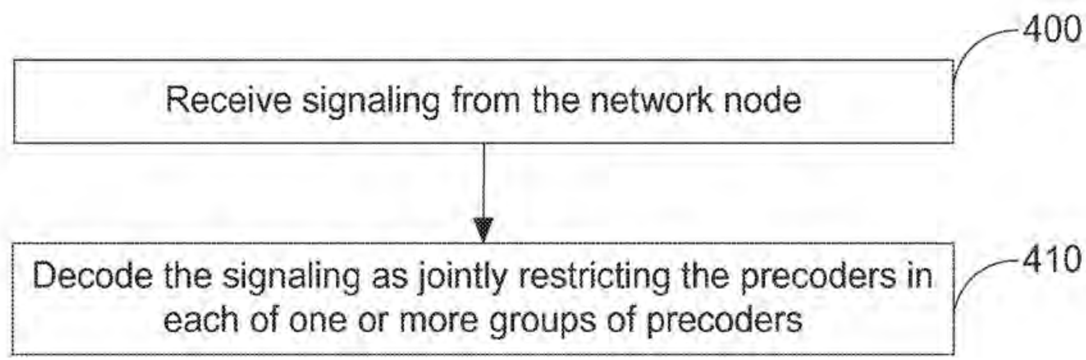

400
Receive signaling from the network node
410
Decode the signaling as jointly restricting the precoders in each of one or more groups of precoders

Figure 10

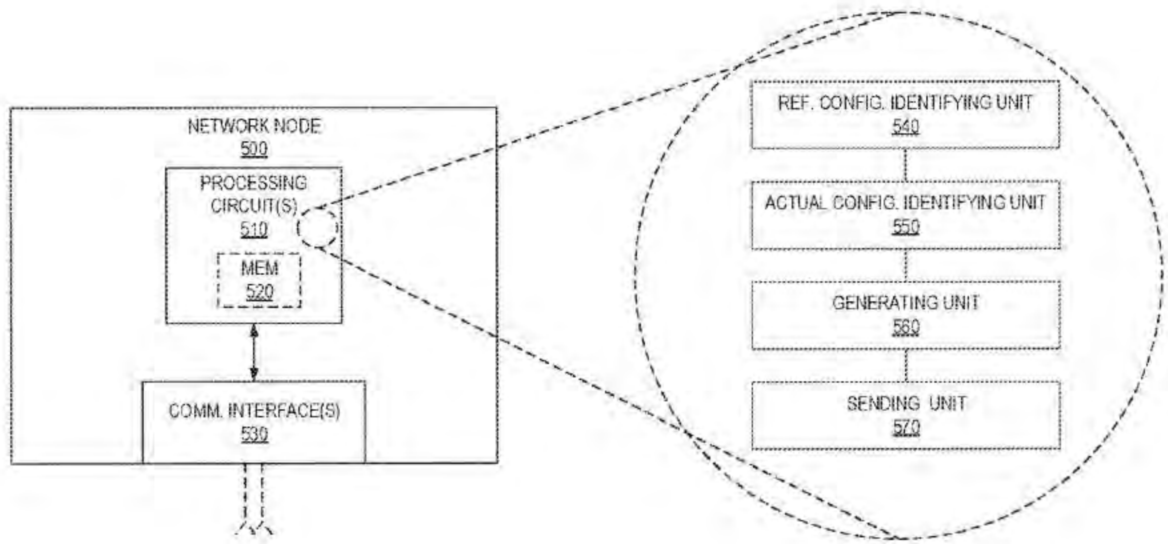

NETWORK NODE
500
PROCESSING
CIRCUIT(S)
510
MEM
520
COMM. INTERFACE(S)
530
REF. CONFIG. IDENTIFYING UNIT
540
ACTUAL CONFIG. IDENTIFYING UNIT
550
GENERATING UNIT
560
SENDING UNIT
570

Figure 11

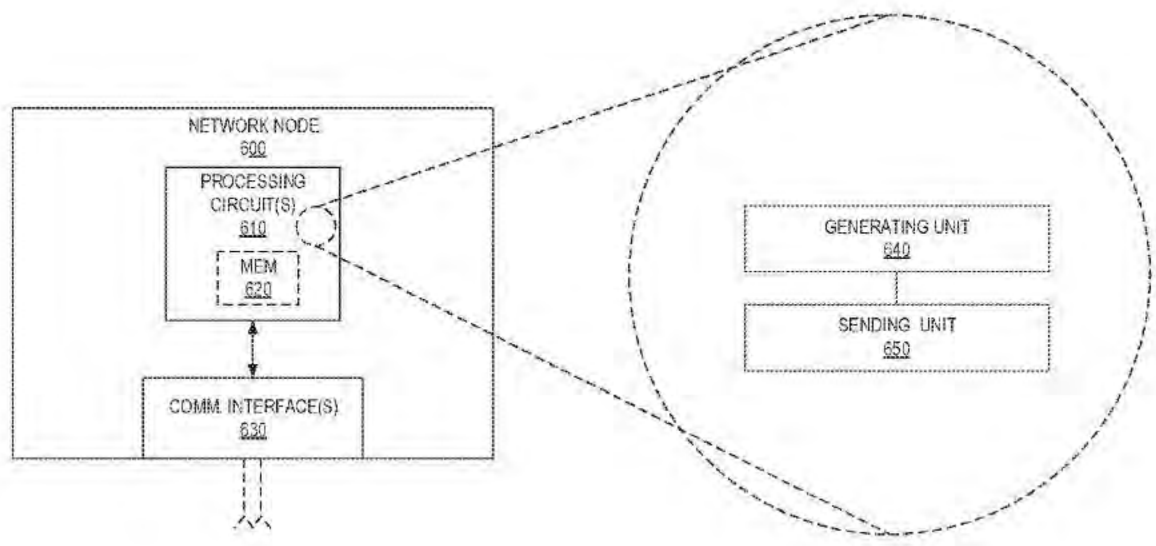

NETWORK NODE
600
PROCESSING
CIRCUIT(S)
610
MEM
620
COMM. INTERFACE(S)
630
GENERATING UNIT
640
SENDING UNIT
650

Figure 12

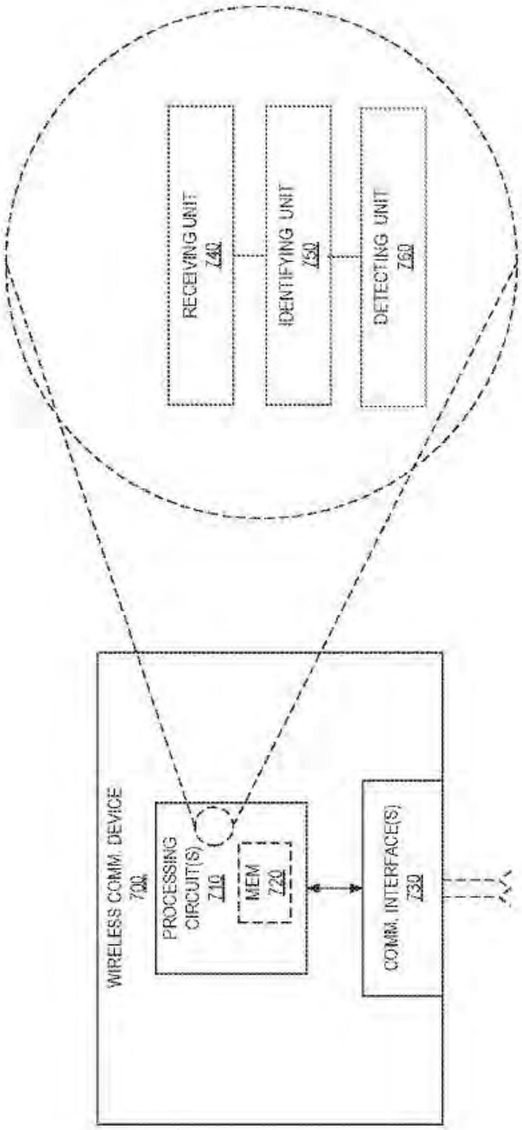
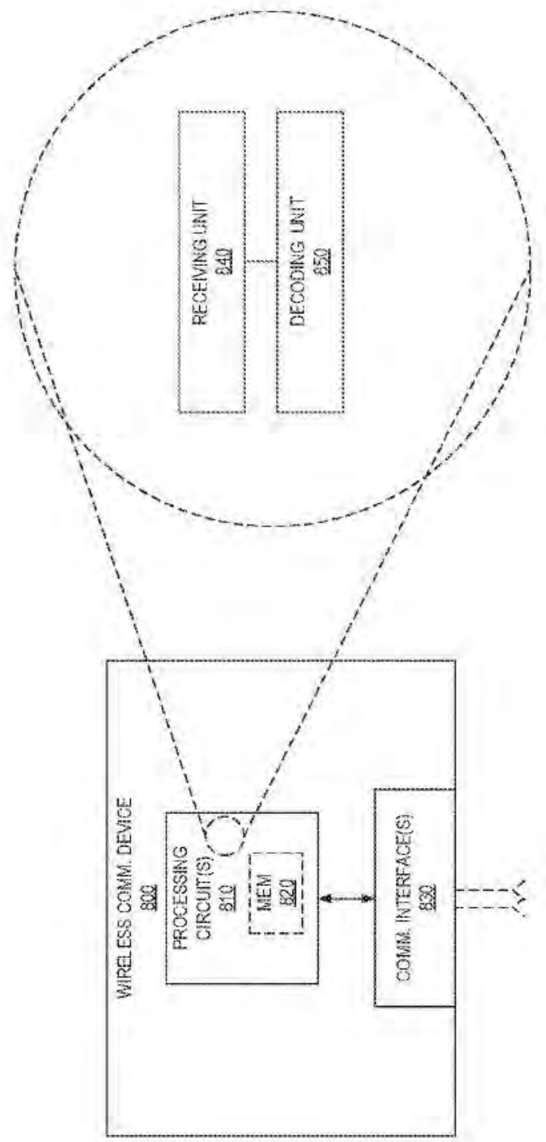

WIRELESS COMM. DEVICE
700
PROCESSING
CIRCUIT(S)
710
MEM
720
COMM. INTERFACE(S)
730
RECEIVING UNIT
740
IDENTIFYING UNIT
750
DETECTING UNIT
760

Figure 13



WIRELESS COMM. DEVICE
800
PROCESSING CIRCUIT(S)
810
MEM
820
COMM. INTERFACE(S)
830
RECEIVING UNIT
840
DECODING UNIT
850

Figure 14

PCT REQUEST

Print Out (Original in Electronic Form)

0	**For receiving Office use only**	
0-1	International Application No.	
0-2	International Filing Date	
0-3	Name of receiving Office and "PCT International Application"	

0-4	**Form PCT/RO/101 PCT Request**	
0-4-1	Prepared Using	PCT Online Filing Version 3.5.000.244e MT/FOP 20141031/0.20.5.20
0-5	**Petition** The undersigned requests that the present international application be processed according to the Patent Cooperation Treaty	
0-6	**Receiving Office (specified by the applicant)**	Swedish Patent and Registration Office (RO/SE)
0-7	**Applicant's or agent's file reference**	P45698WO1
I	**Title of Invention**	CODEBOOK SUBSET RESTRICTION SIGNALING
II	**Applicant**	
II-1	This person is	Applicant only
II-2	Applicant for	All designated States
II-4	Name	Telefonaktiebolaget L M Ericsson (publ)
II-5	Address	SE-164 83 Stockholm Sweden
II-6	State of nationality	SE
II-7	State of residence	SE
II-8	Telephone No.	+46 10 719 0000
II-9	Facsimile No.	+46 10 71 75695
II-10	e-mail	patent.development@ericsson.com
II-10(a)	E-mail authorization The receiving Office, the International Searching Authority, the International Bureau and the International Preliminary Examining Authority are authorized to use this e-mail address, if the Office or Authority so wishes, to send notifications issued in respect of this international application:	exclusively in electronic form (no paper notifications will be sent)

III-1	**Applicant and/or inventor**	
III-1-1	This person is	Inventor only
III-1-3	Inventor for	All designated States
III-1-4	Name (LAST, First)	FAXÉR, Sebastian
III-1-5	Address	Barkarbyvägen 53 D SE-177 44 JÄRFÄLLA Sweden
III-2	**Applicant and/or inventor**	
III-2-1	This person is	Inventor only
III-2-3	Inventor for	All designated States
III-2-4	Name (LAST, First)	WERNERSSON, Niklas
III-2-5	Address	Tunvägen 14 SE-170 68 SOLNA Sweden
III-3	**Applicant and/or inventor**	
III-3-1	This person is	Inventor only
III-3-3	Inventor for	All designated States
III-3-4	Name (LAST, First)	JÄRMYR, Simon
III-3-5	Address	Luftfartsgatan 8 SE-128 34 SKARPNÄCK Sweden
III-4	**Applicant and/or inventor**	
III-4-1	This person is	Inventor only
III-4-3	Inventor for	All designated States
III-4-4	Name (LAST, First)	JÖNGREN, George
III-4-5	Address	Kronogårdsvägen 44 SE-174 62 SUNDBYBERG Sweden
III-5	**Applicant and/or inventor**	
III-5-1	This person is	Inventor only
III-5-3	Inventor for	All designated States
III-5-4	Name (LAST, First)	FRENNE, Mattias
III-5-5	Address	Arkeologvägen 20 SE-754 43 UPPSALA Sweden

PCT REQUEST

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IV-1	**Agent or common representative; or address for correspondence** The person identified below is hereby/ has been appointed to act on behalf of the applicant(s) before the competent International Authorities as:	Agent
IV-1-1	Name (LAST, First)	BOU FAICAL, Roger
IV-1-2	Address	Ericsson AB Patent Unit Kista RAN1 SE-164 80 Stockholm Sweden
IV-1-3	Telephone No.	+46 10 7134981
IV-1-4	Facsimile No.	+46 10 7175695
IV-1-5	e-mail	patent.development@ericsson.com
IV-1-5(a)	E-mail authorization The receiving Office, the International Searching Authority, the International Bureau and the International Preliminary Examining Authority are authorized to use this e-mail address, if the Office or Authority so wishes, to send notifications issued in respect of this international application:	exclusively in electronic form (no paper notifications will be sent)
V	**DESIGNATIONS**	
V-1	**The filing of this request constitutes under Rule 4.9(a), the designation of all Contracting States bound by the PCT on the international filing date, for the grant of every kind of protection available and, where applicable, for the grant of both regional and national patents.**	
VI-1	**Priority claim of earlier national application**	
VI-1-1	Filing date	14 January 2015 (14.01.2015)
VI-1-2	Number	62/103,101
VI-1-3	Country or Member of WTO	US
VI-2	**Priority document request** The International Bureau is requested to obtain from a digital library a certified copy of the earlier application(s) identified above as item(s), using, where applicable, the access code(s) indicated:	VI-1 Access code: 9403

VI-3	**Incorporation by reference :** where an element of the international application referred to in Article 11(1)(iii)(d) or (e) or a part of the description, claims or drawings referred to in Rule 20.5(a) is not otherwise contained in this international application but is completely contained in an earlier application whose priority is claimed on the date on which one or more elements referred to in Article 11(1)(iii) were first received by the receiving Office, that element or part is, subject to confirmation under Rule 20.6, incorporated by reference in this international application for the purposes of Rule 20.6.		
VII-1	**International Searching Authority Chosen**	European Patent Office (EPO) (ISA/EP)	
VIII	**Declarations**	Number of declarations	
VIII-1	Declaration as to the identity of the inventor	-	
VIII-2	Declaration as to the applicant's entitlement, as at the international filing date, to apply for and be granted a patent	-	
VIII-3	Declaration as to the applicant's entitlement, as at the international filing date, to claim the priority of the earlier application	-	
VIII-4	Declaration of inventorship (only for the purposes of the designation of the United States of America)	-	
VIII-5	Declaration as to non-prejudicial disclosures or exceptions to lack of novelty	-	
IX	**Check list**	Number of sheets	Electronic file(s) attached
IX-1	Request (including declaration sheets)	5	✓
IX-2	Description	30	✓
IX-3	Claims	8	✓
IX-4	Abstract	1	✓
IX-5	Drawings	14	✓
IX-7	TOTAL	58	
	Accompanying Items	Paper document(s) attached	Electronic file(s) attached
IX-8	Fee calculation sheet	-	✓
IX-19	Other	Pre-conversion archive	✓
IX-20	**Figure of the drawings which should accompany the abstract**		
IX-21	**Language of filing of the international application**	English	

PCT REQUEST

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X-1	Signature of applicant, agent or common representative	/Roger Bou Faical/
X-1-1	Name (LAST, First)	BOU FAICAL, Roger
X-1-3	Capacity (if such capacity is not obvious from reading the request)	(Representative)

FOR RECEIVING OFFICE USE ONLY

10-1	Date of actual receipt of the purported international application	
10-2	Drawings:	
10-2-1	Received	
10-2-2	Not received	
10-3	Corrected date of actual receipt due to later but timely received papers or drawings completing the purported international application	
10-4	Date of timely receipt of the required corrections under PCT Article 11(2)	
10-5	International Searching Authority	ISA/EP
10-6	Transmittal of search copy delayed until search fee is paid	

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11-1	Date of receipt of the record copy by the International Bureau	

PRV
SWEDISH PATENT AND REGISTRATION OFFICE

Acknowledgement of receipt

We hereby acknowledge receipt of your request for the processing of an international application according to the Patent Cooperation Treaty as follows:

Submission number	1000077276	
PCT application number	PCT/SE2016/050009	
Date of receipt	11 January 2016	
Receiving Office	Swedish Patent and Registration Office	
Your reference	P45698WO1	
Applicant	Telefonaktiebolaget L M Ericsson (publ)	
Number of applicants	1	
Country	SE	
Title	CODEBOOK SUBSET RESTRICTION SIGNALING	
Documents submitted	eolf-pkda.xml	eolf-requ.xml
	eolf-appb.xml	eolf-fees.xml
	eolf-vlog.xml	eolf-othd-000001.pdf (39 p.)
	eolf-abst.txt	eolf-appb-P000001.pdf (14 p.)
	eolf-othd-000002.zip	
Submitted by	CN=Renee Ahlund 1553	
Method of submission	Online	
Date and time receipt generated	11 January 2016, 15:27:36 (CET)	
Digest	54:A5:34:88:2A:C1:24:62:77:EE:80:DD:EF:29:79:BF:86:D3:EF:D2	

/Swedish Patent and Registration Office/

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of **Faxér** *et al.*	)	
Serial No.: **TBD**	)	Examiner: **TBD**
Filed: **TBD**	)	Group Art Unit: **TBD**
For: **Codebook Subset Restriction Signaling**	)	
Attorney's Docket No: **4015-9595 / P45698-US2**	)	

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Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

PRELIMINARY AMENDMENT

Please be advised that this is a **U.S. National Stage Filing of PCT Application PCT/SE2016/050009.**

Prior to examination, please amend the application as indicated below.

AMENDMENTS TO THE CLAIMS

1-38. (Cancelled)

39. (New) A method implemented by a network node for signaling to a wireless communication device which precoders in a codebook are restricted from being used, the method characterized by:

generating codebook subset restriction signaling that, for each of one or more groups of precoders, jointly restricts the precoders in the group by restricting a certain component that the precoders in the group have in common; and

sending the generated signaling from the network node to the wireless communication device.

40. (New) The method of claim 39, wherein the codebook subset restriction signaling is rank-agnostic signaling that jointly restricts the precoders in a group without regard to the precoders' transmission rank.

41. (New) The method of claim 39, wherein a precoder comprising one or more beam precoders is restricted if at least one of its one or more beam precoders is restricted.

42. (New) The method of claim 39, wherein the certain component comprises a beam precoder.

43. (New) The method of claim 42, wherein a beam precoder is a Kronecker product of different beamforming vectors associated with different dimensions of a multi-dimensional antenna array.

44. (New) The method of claim 43, wherein the different beamforming vectors comprise Discrete Fourier Transform (DFT) vectors.

45. (New) The method of claim 42, wherein a beam precoder is a beamforming vector used to transmit on a particular layer of a multi-layer transmission, wherein different scaled versions of that beamforming vector are transmitted on different polarizations;

46. (New) The method of claim 39, wherein a beam precoder is a Kronecker product of first and second beamforming vectors with first and second indices, wherein the first and second beamforming vectors are associated with different dimensions of a multi-dimensional antenna array, and wherein the codebook subset restriction signaling jointly restricts the precoders in a group of precoders that have the same pair of values for the first and second indices.

47. (New) A method implemented by a wireless communication device for decoding signaling from a network node indicating which precoders in a codebook are restricted from being used, the method characterized by:

receiving codebook subset restriction signaling that, for each of one or more groups of precoders, jointly restricts the precoders in the group by restricting a certain component that the precoders in the group have in common; and

decoding the received signaling as jointly restricting precoders in each of the one or more groups of precoders.

48. (New) The method of claim 47, wherein the codebook subset restriction signaling is rank-agnostic signaling that jointly restricts the precoders in a group without regard to the precoders' transmission rank.

49. (New) The method of claim 47, wherein a precoder comprising one or more beam precoders is restricted if at least one of its one or more beam precoders is restricted.

50. (New) The method of claim 47, wherein the certain component comprises a beam precoder.

51. (New) The method of claim 50, wherein a beam precoder is a Kronecker product of different beamforming vectors associated with different dimensions of a multi-dimensional antenna array.

52. (New) The method of claim 51, wherein the different beamforming vectors comprise Discrete Fourier Transform (DFT) vectors.

53. (New) The method of claim 50, wherein a beam precoder is a beamforming vector used to transmit on a particular layer of a multi-layer transmission, wherein different scaled versions of that beamforming vector are transmitted on different polarizations;

54. (New) The method of claim 47, wherein a beam precoder is a Kronecker product of first and second beamforming vectors with first and second indices, wherein the first and second beamforming vectors are associated with different dimensions of a multi-dimensional antenna array, and wherein the codebook subset restriction signaling jointly restricts the precoders in a group of precoders that have the same pair of values for the first and second indices.

55. (New) A network node for signaling to a wireless communication device which precoders in a codebook are restricted from being used, the network node comprising:

a processor and a memory, the memory containing instructions executable by the processor whereby the network node is configured to:

generate codebook subset restriction signaling that, for each of one or more groups of precoders, jointly restricts the precoders in the group by restricting a certain component that the precoders in the group have in common; and

send the generated signaling from the network node to the wireless communication device.

56. (New) The network node of claim 55, wherein the codebook subset restriction signaling is rank-agnostic signaling that jointly restricts the precoders in a group without regard to the precoders' transmission rank.

57. (New) The network node of claim 55, wherein a precoder comprising one or more beam precoders is restricted if at least one of its one or more beam precoders is restricted.

58. (New) The network node of claim 55, wherein the certain component comprises a beam precoder.

59. (New) The network node of claim 58, wherein a beam precoder is a Kronecker product of different beamforming vectors associated with different dimensions of a multi-dimensional antenna array.

60. (New) The network node of claim 59, wherein the different beamforming vectors comprise Discrete Fourier Transform (DFT) vectors.

61. (New) The network node of claim 58, wherein a beam precoder is a beamforming vector used to transmit on a particular layer of a multi-layer transmission, wherein different scaled versions of that beamforming vector are transmitted on different polarizations;

62. (New) The network node of claim 55, wherein a beam precoder is a Kronecker product of first and second beamforming vectors with first and second indices, wherein the first and second beamforming vectors are associated with different dimensions of a multi-dimensional antenna array, and wherein the codebook subset restriction signaling jointly restricts the precoders in a group of precoders that have the same pair of values for the first and second indices.

63. (New) A wireless communication device for decoding signaling from a network node indicating which precoders in a codebook are restricted from being used, the wireless communication device comprising:

a processor and a memory, the memory containing instructions executable by the processor whereby the wireless communication device is configured to:

receive codebook subset restriction signaling that, for each of one or more groups of precoders, jointly restricts the precoders in the group by restricting a certain component that the precoders in the group have in common; and

decode the received signaling as jointly restricting precoders in each of the one or more groups of precoders.

64. (New) The wireless communication device of claim 63, wherein the codebook subset restriction signaling is rank-agnostic signaling that jointly restricts the precoders in a group without regard to the precoders' transmission rank.

65. (New) The wireless communication device of claim 63, wherein a precoder comprising one or more beam precoders is restricted if at least one of its one or more beam precoders is restricted.

66. (New) The wireless communication device of claim 63, wherein the certain component comprises a beam precoder.

67. (New) The wireless communication device of claim 66, wherein a beam precoder is a Kronecker product of different beamforming vectors associated with different dimensions of a multi-dimensional antenna array.

68. (New) The wireless communication device of claim 67, wherein the different beamforming vectors comprise Discrete Fourier Transform (DFT) vectors.

69. (New) The wireless communication device of claim 66, wherein a beam precoder is a beamforming vector used to transmit on a particular layer of a multi-layer transmission, wherein different scaled versions of that beamforming vector are transmitted on different polarizations;

70. (New) The wireless communication device of claim 63, wherein a beam precoder is a Kronecker product of first and second beamforming vectors with first and second indices, wherein the first and second beamforming vectors are associated with different dimensions of a multi-dimensional antenna array, and wherein the codebook subset restriction signaling jointly restricts the precoders in a group of precoders that have the same pair of values for the first and second indices.

REMARKS

The foregoing claim amendments are submitted prior to examination on the merits. The amendments cancel claims 1-38, and add new claims 39-70. New claims 39-70 are similar to selected ones of now canceled claims 1-38, but are written to eliminate multiple dependent claims, and to better comport the language of the claims with U.S. practice. No new matter has been added, and the amendments are not submitted for reasons related to patentability over any prior art.

Entry of the amendments is requested prior to examination on the merits.

Respectfully submitted,
COATS & BENNETT P.L.L.C.

Justin Leonard

Date: June 17, 2016

Justin J. Leonard
Registration No. 60,986
Telephone: (919) 854-1844

Replaces PTO/AIA/01 (06-12)

DECLARATION (37 CFR 1.63) FOR UTILITY OR DESIGN APPLICATION USING AN APPLICATION DATA SHEET (37 CFR 1.76)	Attorney Docket Number	P45698 WO1

Title of Invention	CODEBOOK SUBSET RESTRICTION SIGNALING

As the below named inventor, I hereby declare that:

This declaration is directed to:

☒ The attached application, or

☐ United States application or PCT international application number PCT/SE2016/050009, filed on January 11, 2016

The above-identified application was made or authorized to be made by me.

I believe that I am the original inventor or an original joint inventor of a claimed invention in the application.

I have reviewed and understand the contents of the above identified application, including the claims, as amended by any amendment specifically referred to above.

I am aware of the duty to disclose information which is material to patentability as defined in 37 CFR 1.56, including for continuation-in-part applications, material information which became available between the filing date of the prior application and the national or PCT international filing date of the continuation-in-part application.

I hereby acknowledge that any willful false statement made in this declaration is punishable under 18 U.S.C. 1001 by fine or imprisonment of not more than five (5) years, or both.

LEGAL NAME OF INVENTOR

Inventor: Niklas Wernersson

Date (Optional): 2016-02-15

Signature: [signature]

Replaces PTO/AIA/01 (06-12)

DECLARATION (37 CFR 1.63) FOR UTILITY OR DESIGN APPLICATION USING AN APPLICATION DATA SHEET (37 CFR 1.76)	Attorney Docket Number	P45698 WO1

Title of Invention	CODEBOOK SUBSET RESTRICTION SIGNALING

As the below named inventor, I hereby declare that:

This declaration is directed to:

☐ The attached application, or

☒ United States application or PCT international application number PCT/SE2016/050009, filed on January 11, 2016

The above-identified application was made or authorized to be made by me.

I believe that I am the original inventor or an original joint inventor of a *claimed invention* in the application.

I have reviewed and understand the contents of the above identified application, including the claims, as amended by any amendment specifically referred to above.

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I hereby acknowledge that any willful false statement made in this declaration is punishable under 18 U.S.C. 1001 by fine or imprisonment of not more than five (5) years, or both.

LEGAL NAME OF INVENTOR

Inventor: Simon Järmyr Date (Optional):

Signature:

DECLARATION (37 CFR 1.63) FOR UTILITY OR DESIGN APPLICATION USING AN APPLICATION DATA SHEET (37 CFR 1.76)	Attorney Docket Number	P45698 WO1

Title of Invention	CODEBOOK SUBSET RESTRICTION SIGNALING

As the below named inventor, I hereby declare that:

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☐ The attached application, or

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I hereby acknowledge that any willful false statement made in this declaration is punishable under 18 U.S.C. 1001 by fine or imprisonment of not more than five (5) years, or both.

LEGAL NAME OF INVENTOR

Inventor: Sebastian Faxér — Date (Optional): 2016-01-25

Signature: [signature]

Replaces PTO/AIA/01 (06-12)

DECLARATION (37 CFR 1.63) FOR UTILITY OR DESIGN APPLICATION USING AN APPLICATION DATA SHEET (37 CFR 1.76)	Attorney Docket Number	P45698 WO1

Title of Invention	CODEBOOK SUBSET RESTRICTION SIGNALING

As the below named inventor, I hereby declare that:

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I hereby acknowledge that any willful false statement made in this declaration is punishable under 18 U.S.C. 1001 by fine or imprisonment of not more than five (5) years, or both.

LEGAL NAME OF INVENTOR

Inventor: George Jöngren Date (Optional):

Signature:

Replaces PTO/AIA/01 (06-12)

DECLARATION (37 CFR 1.63) FOR UTILITY OR DESIGN APPLICATION USING AN APPLICATION DATA SHEET (37 CFR 1.76)	Attorney Docket Number	P45698 WO1

Title of Invention	CODEBOOK SUBSET RESTRICTION SIGNALING

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I hereby acknowledge that any willful false statement made in this declaration is punishable under 18 U.S.C. 1001 by fine or imprisonment of not more than five (5) years, or both.

LEGAL NAME OF INVENTOR

Inventor: Mattias Frenne

Date (Optional): 2016-01-25

Signature: Matt Fr

POWER OF ATTORNEY

The undersigned, being duly authorized representatives of **TELEFONAKTIEBOLAGET LM ERICSSON (PUBL)** (hereafter referred to as "Ericsson") having its registered office as SE - 164 83 Stockholm, Sweden, does hereby authorize **Coats & Bennett, PLLC practitioners associated with United States Patent and Trademark Office Customer Number 24112** to represent Ericsson before the United States Patent and Trademark Office in any and all matters regarding patents or patent applications filed by Ericsson or wherein Ericsson is the assignee of the entire interest thereto.

This Power of Attorney shall include the right for **Coats & Bennett, PLLC practitioners associated with United States Patent and Trademark Office Customer Number 24112** to sign and submit in Ericsson's name and on Ericsson's behalf any document, notification, filing, petition or request in connection with any patent applications or patents owned by or assigned to Ericsson.

This Power of Attorney does not include the right to appoint substitutes or make sub-authorizations.

This Power of Attorney shall be valid for **five (5) years** from the date hereof unless earlier revoked. This Power of Attorney may be revoked at any time by Ericsson.

Stockholm, Sweden on

TELEFONAKTIEBOLAGET LM ERICSSON (PUBL)

Signature: [signature] [signature]

Gabriele Mohsler	Nabil Ayoub
Vice President Patent Development	Director Patent Unit RAN2

Date: 2016-04-05

I, the undersigned, ____________________, Notary Public of the City of Stockholm hereby certify that ________________ and ________________

duly authorized to sign for

TELEFONAKTIEBOLAGET LM ERICSSON (PUBL)

have issued and signed the foregoing document

Fee	**Stockholm [Date]**
Crowns	**Ex officio:**

____

Signature: Notary Public of the City of Stockholm

PTO/AIA/96 (08-12)
Approved for use through 01/31/2013. OMB 0651-0031
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

STATEMENT UNDER 37 CFR 3.73(c)

Applicant/Patent Owner: Telefonaktiebolaget LM Ericsson (publ)

Application No./Patent No.: TBA Filed/Issue Date: TBA

Titled: Codebook Subset Restriction Signaling

Telefonaktiebolaget LM Ericsson (publ), a corporation

(Name of Assignee) (Type of Assignee, e.g., corporation, partnership, university, government agency, etc.)

states that, for the patent application/patent identified above, it is (choose **one** of options 1, 2, 3 or 4 below):

1. ☑ The assignee of the entire right, title, and interest.

2. ☐ An assignee of less than the entire right, title, and interest (check applicable box):

☐ The extent (by percentage) of its ownership interest is ________%. Additional Statement(s) by the owners holding the balance of the interest must be submitted to account for 100% of the ownership interest.

☐ There are unspecified percentages of ownership. The other parties, including inventors, who together own the entire right, title and interest are:

Additional Statement(s) by the owner(s) holding the balance of the interest must be submitted to account for the entire right, title, and interest.

3. ☐ The assignee of an undivided interest in the entirety (a complete assignment from one of the joint inventors was made). The other parties, including inventors, who together own the entire right, title, and interest are:

Additional Statement(s) by the owner(s) holding the balance of the interest must be submitted to account for the entire right, title, and interest.

4. ☐ The recipient, via a court proceeding or the like (*e.g.*, bankruptcy, probate), of an undivided interest in the entirety (a complete transfer of ownership interest was made). The certified document(s) showing the transfer is attached.

The interest identified in option 1, 2 or 3 above (not option 4) is evidenced by either (choose **one** of options A or B below):

A. ☑ An assignment from the inventor(s) of the patent application/patent identified above. The assignment was recorded in the United States Patent and Trademark Office at Reel ________, Frame ________, or for which a copy thereof is attached.

B. ☐ A chain of title from the inventor(s), of the patent application/patent identified above, to the current assignee as follows:

1. From: ________________ To: ________________

The document was recorded in the United States Patent and Trademark Office at

Reel ________, Frame ________, or for which a copy thereof is attached.

2. From: ________________ To: ________________

The document was recorded in the United States Patent and Trademark Office at

Reel ________, Frame ________, or for which a copy thereof is attached.

PTO/AIA/96 (08-12)
Approved for use through 01/31/2013. OMB 0651-0031
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

STATEMENT UNDER 37 CFR 3.73(c)

3. From: ______________________ To: ______________________

The document was recorded in the United States Patent and Trademark Office at

Reel ________, Frame ________, or for which a copy thereof is attached.

4. From: ______________________ To: ______________________

The document was recorded in the United States Patent and Trademark Office at

Reel ________, Frame ________, or for which a copy thereof is attached.

5. From: ______________________ To: ______________________

The document was recorded in the United States Patent and Trademark Office at

Reel ________, Frame ________, or for which a copy thereof is attached.

6. From: ______________________ To: ______________________

The document was recorded in the United States Patent and Trademark Office at

Reel ________, Frame ________, or for which a copy thereof is attached.

☐ Additional documents in the chain of title are listed on a supplemental sheet(s).

☑ As required by 37 CFR 3.73(c)(1)(i), the documentary evidence of the chain of title from the original owner to the assignee was, or concurrently is being, submitted for recordation pursuant to 37 CFR 3.11.

[NOTE: A separate copy (i.e., a true copy of the original assignment document(s)) must be submitted to Assignment Division in accordance with 37 CFR Part 3, to record the assignment in the records of the USPTO. See MPEP 302.08]

The undersigned (whose title is supplied below) is authorized to act on behalf of the assignee.

/ Justin J. Leonard /	2016-06-17
Signature	Date
Justin J. Leonard	60986
Printed or Typed Name	Title or Registration Number

Privacy Act Statement

The **Privacy Act of 1974 (P.L. 93-579)** requires that you be given certain information in connection with your submission of the attached form related to a patent application or patent. Accordingly, pursuant to the requirements of the Act, please be advised that: (1) the general authority for the collection of this information is 35 U.S.C. 2(b)(2); (2) furnishing of the information solicited is voluntary; and (3) the principal purpose for which the information is used by the U.S. Patent and Trademark Office is to process and/or examine your submission related to a patent application or patent. If you do not furnish the requested information, the U.S. Patent and Trademark Office may not be able to process and/or examine your submission, which may result in termination of proceedings or abandonment of the application or expiration of the patent.

The information provided by you in this form will be subject to the following routine uses:

1. The information on this form will be treated confidentially to the extent allowed under the Freedom of Information Act (5 U.S.C. 552) and the Privacy Act (5 U.S.C 552a). Records from this system of records may be disclosed to the Department of Justice to determine whether disclosure of these records is required by the Freedom of Information Act.
2. A record from this system of records may be disclosed, as a routine use, in the course of presenting evidence to a court, magistrate, or administrative tribunal, including disclosures to opposing counsel in the course of settlement negotiations.
3. A record in this system of records may be disclosed, as a routine use, to a Member of Congress submitting a request involving an individual, to whom the record pertains, when the individual has requested assistance from the Member with respect to the subject matter of the record.
4. A record in this system of records may be disclosed, as a routine use, to a contractor of the Agency having need for the information in order to perform a contract. Recipients of information shall be required to comply with the requirements of the Privacy Act of 1974, as amended, pursuant to 5 U.S.C. 552a(m).
5. A record related to an International Application filed under the Patent Cooperation Treaty in this system of records may be disclosed, as a routine use, to the International Bureau of the World Intellectual Property Organization, pursuant to the Patent Cooperation Treaty.
6. A record in this system of records may be disclosed, as a routine use, to another federal agency for purposes of National Security review (35 U.S.C. 181) and for review pursuant to the Atomic Energy Act (42 U.S.C. 218(c)).
7. A record from this system of records may be disclosed, as a routine use, to the Administrator, General Services, or his/her designee, during an inspection of records conducted by GSA as part of that agency's responsibility to recommend improvements in records management practices and programs, under authority of 44 U.S.C. 2904 and 2906. Such disclosure shall be made in accordance with the GSA regulations governing inspection of records for this purpose, and any other relevant (*i.e.*, GSA or Commerce) directive. Such disclosure shall not be used to make determinations about individuals.
8. A record from this system of records may be disclosed, as a routine use, to the public after either publication of the application pursuant to 35 U.S.C. 122(b) or issuance of a patent pursuant to 35 U.S.C. 151. Further, a record may be disclosed, subject to the limitations of 37 CFR 1.14, as a routine use, to the public if the record was filed in an application which became abandoned or in which the proceedings were terminated and which application is referenced by either a published application, an application open to public inspection or an issued patent.
9. A record from this system of records may be disclosed, as a routine use, to a Federal, State, or local law enforcement agency, if the USPTO becomes aware of a violation or potential violation of law or regulation.

ASSIGNMENT

This Assignment is made by:

FAXÉR, Sebastian — **Barkarbyvägen 53 D**
SE-177 44 JÄRFÄLLA

Sweden

FRENNE, Mattias — **Arkeologvägen 20**
SE-754 43 UPPSALA

Sweden

JÄRMYR, Simon — **Luftfartsgatan 8**
SE-128 34 SKARPNÄCK

Sweden

JÖNGREN, George — **Kronogårdsvägen 44**
SE-174 62 SUNDBYBERG

Sweden

WERNERSSON, Niklas — **Tunvägen 14**
SE-170 68 SOLNA

Sweden

(hereinafter referred to as "Assignor(s)") in favor, and for the benefit and behoof of, Telefonaktiebolaget LM Ericsson (publ), a corporation duly organized under and pursuant to the laws of Sweden and having its principal place of business at SE-164 83 Stockholm, Sweden (hereinafter referred to as "Assignee").

For good, sufficient and adequate consideration, the receipt of which is hereby acknowledged, the Assignor(s) have, as of the Effective Date, sold, assigned, transferred, and set over, and by these presents, and to the extent any transferable or assignable rights still remain with the inventor, do hereby sell, assign, transfer, and set over, unto the Assignee, its successors, legal representatives, and assigns the entire right, title, and interest in and to the following inventions, application(s) for Letters Patent, and any and all Letters Patent or Patents in all countries and pursuant to all multilateral treaty organizations, including Sweden, the United States of America, the Patent Cooperation Treaty and European Patent Convention, that may be granted therefor and thereon, and in and to any and all divisions, continuations, continuations-in-part, conversions and utility models of said application(s), and reissues and extensions of said Letters Patent or Patents, the same to be held and enjoyed by the Assignee, for its use and behoof and the use and the behoof of its successors, legal representatives, and assigns, to the full end of the term or terms for which Letters Patent, Patents and Utility Models may be granted as fully and entirely as the same would have been held and enjoyed by the Assignor(s) had this sale and assignment not been made:

CODEBOOK SUBSET RESTRICTION SIGNALING

ASSIGNMENT

including, but not limited to, the application(s) for Letters Patent and Utility Model filed in:

Country Code	Priority Application(s)	Filing Date(s)
WO	PCT/SE2016/050009	2016-01-11
		- -

The Effective date is the earliest date of the above listed Filing Date(s).

Assignor(s) hereby authorize and request Assignee's Attorneys to insert the serial number and filing date of said application(s) for Letter Patent or Utility Model, when known. The assignment of the above mentioned rights includes a transfer of the whole right to use a priority (including priority according to any convention, multilateral agreement, bilateral agreement and national law) of the above mentioned application(s) for Letter Patent and Utility Model in all countries and multilateral treaty organizations wherein no residual rights shall remain with the Assignor(s). Assignor(s) hereby request that said Letters Patent, Patent or Utility Model be issued to Assignee as the Assignee of said inventions, the Letters Patent, Patent or Utility Model to be issued for the sole use and behoof of the Assignee, its successors, legal representatives, and assigns. Assignee alone hereinafter has the entire disposal of the invention and possesses entire ownership to any domestic and foreign patents or utility models granted thereinafter. The rights granted hereunder shall include all rights to institute legal actions, obtain remedies and recover and retain damages in respect to said Letters Patent, Patent or Utility Model.

The Assignor(s) and Assignee hereby understand and agree that with the execution of this Assignment, to the extent necessary or appropriate, national and/or regional applications may be filed by the Assignee as the applicant and on behalf of the assignor.

To the extent Assignee is entitled to receive the rights hereunder pursuant to this Assignment, each of the Assignor(s) hereby covenants and agrees to and with the Assignee, its successors, legal representatives, and assigns, that, at the time of the Effective Date, the Assignor(s) were the sole and lawful owners of the entire right, title, and interest in and to the inventions and application(s) for Letters Patent or Utility Models above-mentioned, and that the same are unencumbered, and that the Assignor(s) have good and full right and lawful authority to sell and convey the same in the manner herein set forth.

Further, and for the same consideration, the Assignor(s) hereby covenant(s) and agree(s) to and with the Assignee, its successors, legal representatives, and assigns that the Assignor(s) will, whenever counsel of the Assignee, or the counsel of its successors, legal representatives, and assigns, shall advise that any proceeding in connection with said inventions or said application(s) for Letters Patent or Utility Model, or any proceeding in connection with Letters Patent or Utility Model for said inventions, in any country and any multilateral treaty organization, including interference proceedings, is lawful and desirable, or that any division, continuation, continuation-in-part, conversion or Utility Model of any application(s) for Letters Patent or Utility Model, or any reissue or extension of any Letters Patent to be obtained thereon, is lawful and desirable, sign all papers and documents, take all lawful oaths, and do all acts necessary or required to be done for the procurement, maintenance, enforcement, and defense of Letters Patent or Utility Model for said inventions, without charge to Assignee, its successors, legal representatives, and

ASSIGNMENT

assigns, but at the cost and expense of the Assignee, its successors, legal representatives, and assigns. If any of the Assignor(s) is prevented by any obstacles from signing said documents in person, this Assignment shall be valid as a Power of Attorney for the Assignee to sign these documents on behalf of any such Assignor(s) or, in the event of the death of the latter, the estate thereof.

This Assignment shall be governed by and construed under, and any dispute, controversy or claim related hereto shall be decided in accordance with, the laws of:
Sweden

without regard to the conflicts of laws provisions thereof. Any dispute, controversy or claim arising under, out of or relating to this Assignment and any subsequent amendments of this Assignment, including, without limitation, its formation, validity, binding effect, interpretation, performance, breach or termination, as well as non-contractual claims, shall be referred to and finally determined by arbitration in accordance with the WIPO Arbitration Rules. The arbitral tribunal shall consist of a sole arbitrator. The place of arbitration shall be in the country of the inventor's residence. The language to be used in the arbitral proceedings shall be English.

No modifications shall be made to this Assignment unless in writing and signed by each of the Assignor(s) and Assignee. If any of the provisions of this Assignment shall be deemed invalid or unenforceable, then the entire Assignment shall be construed as if not containing the particular invalid or unenforceable provision or provisions, and the rights and obligations of Assignee and Assignor(s) shall be construed and enforced accordingly. Assignee's failure to exercise any option made available as a result hereof, shall not be construed as a waiver of such provisions, rights, or options, or affect the validity of this Assignment. Assignor covenants and agrees that it will not take any actions in violation of this Assignment.

Subsequent assignment from any of the assignors to the assignee purporting to convey the subject matter specified herein for a particular country, patent office, or jurisdiction shall not invalidate any provision of this assignment and any such subsequent assignment shall act as a further confirmation of the assignment herein.

Date 2016-06-07 .... Signature on behalf of Assignee .... Roger Bou Faical

ASSIGNMENT

Title: CODEBOOK SUBSET RESTRICTION SIGNALING

Date 2016-01-25 Signature of Assignor ....
FAXÉR, Sebastian

Date 2016-01-25 Witnessed by ....
Name: Erik Dahlman
Address: Schedcgatan 3
12233 Stockholm

Date 2016-01-25 Witnessed by ....
Name: Svante Bergman
Address: Selmedalsvägen 8
12936 Hägersten
Sweden

ASSIGNMENT

Title: CODEBOOK SUBSET RESTRICTION SIGNALING

Date 2016-01-25 .... Signature of Assignor ....

FRENNE, Mattias

Date 2016-01-25 .... Witnessed by ....

Name: Håkan Persson

Address: Krysshammarv. 22

17172 SOLNA

SWEDEN

Date 2016-01-25 .... Witnessed by ....

Name: Lars Lindbom

Address: Forsgatan 7

65462 Karlstad

SWEDEN

ASSIGNMENT

Title: CODEBOOK SUBSET RESTRICTION SIGNALING

Date 2016-01-25 Signature of Assignor

JARMYR, Simon

Date 2016-01-25 Witnessed by

Name: Maksym Girnyk

Address: Professorslingan 37

11417 Stockholm

Sweden

Date 2016-01-25 Witnessed by

Name: Rickard Abrahamsson

Address: Åsgatan 45

741 45 Knivsta

Sweden

ASSIGNMENT

Title: CODEBOOK SUBSET RESTRICTION SIGNALING

Date 2016-05-23 Signature of Assignor [signature]
JÖNGREN, George

Date 2016-05-23 Witnessed by [signature]

Name: MAKSYM GIRNYK

Address: Professorsslingan 37
114 17 Stockholm
Sweden

Date 2016-05-23 Witnessed by [signature]

Name: Hafiz Shokri Razaghi

Address: Hanstavägen 49 lgh 1645
16543 Kista
Sweden

ASSIGNMENT

Title: CODEBOOK SUBSET RESTRICTION SIGNALING

Date 2016-02-15 Signature of Assignor [signature]

WERNERSSON, Niklas

Date 2016-02-15 Witnessed by [signature]

Name: BARBARA REGAI

Address: TUNV. 14

17068 SOLNA

SWEDEN

Date 2016-02-15 Witnessed by [signature]

Name: Diana Caraghiaur

Address: Tunvägen 14

17068 Solna

Sweden

PTO/SB/08a (03-15)
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INFORMATION DISCLOSURE STATEMENT BY APPLICANT (**Not for submission under 37 CFR 1.99)**		
	Application Number	
	Filing Date	
	First Named Inventor	Faxér
	Art Unit	
	Examiner Name	
	Attorney Docket Number	4015-9595 / P45698-US2

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	1	20110243098	A1	2011-11-06	Koivisto et al.	
	2	20130163687	A1	2013-06-27	Jing et al.	

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INFORMATION DISCLOSURE STATEMENT BY APPLICANT (**Not for submission under 37 CFR 1.99)**	Application Number	
	Filing Date	
	First Named Inventor	Faxér
	Art Unit	
	Examiner Name	
	Attorney Docket Number	4015-9595 / P45698-US2

Examiner Initials*	Cite No	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc), date, pages(s), volume-issue number(s), publisher, city and/or country where published.	T[5]
	1	ERICSSON, "Remaining Details of Codebook Subset Restriction", 3GPP TSG-RAN WG1#83, Anaheim, USA, 2015-11-15, pp. 1-6, R1-157203, 3GPP	
	2	AT&T, "WF on class A and class B CSI reporting for Rel.13 EB FD-MIMO", 3GPP TSG RAN WG1 Meeting #82bis, Malmö, Sweden, 2015-10-05, pp. 1-10, R1-156165, 3GPP	

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EXAMINER SIGNATURE

Examiner Signature		Date Considered	

*EXAMINER: Initial if reference considered, whether or not citation is in conformance with MPEP 609. Draw line through a citation if not in conformance and not considered. Include copy of this form with next communication to applicant.

[1] See Kind Codes of USPTO Patent Documents at www.USPTO.GOV or MPEP 901.04. [2] Enter office that issued the document, by the two-letter code (WIPO Standard ST.3). [3] For Japanese patent documents, the indication of the year of the reign of the Emperor must precede the serial number of the patent document. [4] Kind of document by the appropriate symbols as indicated on the document under WIPO Standard ST.16 if possible. [5] Applicant is to place a check mark here if English language translation is attached.

INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99)	Application Number		
	Filing Date		
	First Named Inventor	Faxér	
	Art Unit		
	Examiner Name		
	Attorney Docket Number		4015-9595 / P45698-US2

CERTIFICATION STATEMENT

Please see 37 CFR 1.97 and 1.98 to make the appropriate selection(s):

That each item of information contained in the information disclosure statement was first cited in any communication from a foreign patent office in a counterpart foreign application not more than three months prior to the filing of the information disclosure statement. See 37 CFR 1.97(e)(1).

OR

☐ That no item of information contained in the information disclosure statement was cited in a communication from a foreign patent office in a counterpart foreign application, and, to the knowledge of the person signing the certification after making reasonable inquiry, no item of information contained in the information disclosure statement was known to any individual designated in 37 CFR 1.56(c) more than three months prior to the filing of the information disclosure statement. See 37 CFR 1.97(e)(2).

See attached certification statement.

The fee set forth in 37 CFR 1.17 (p) has been submitted herewith.

☒ A certification statement is not submitted herewith.

SIGNATURE

A signature of the applicant or representative is required in accordance with CFR 1.33, 10.18. Please see CFR 1.4(d) for the form of the signature.

Signature	/ Justin J. Leonard /	Date (YYYY-MM-DD)	2016-06-17
Name/Print	Justin J. Leonard	Registration Number	60986

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3GPP TSG RAN WG1 Meeting #82bis **R1-156165**
Malmö, Sweden, 5th - 9th October 2015

AI: 7.2.4.3

WF on class A and class B CSI reporting for Rel.13 EB/FD-MIMO

AT&T, Beijing Xinwei Telecom Tech., CATR, CATT, CHTTL, CMCC, Deutsche Telekom, Ericsson, ETRI, Huawei, HiSilicon, ITRI, Kathrein-Werke KG, KDDI, KT Corporation, Nokia Networks, NTT DOCOMO, Samsung, Sony Corporation

Background: Class A codebook structure (R1-154861)

- For each of [8], 12 and 16 Tx ports, a precoding matrix $\boldsymbol{W}$ in the codebook is represented as:

$$\boldsymbol{W} = \boldsymbol{W}_1 \boldsymbol{W}_2$$

where:

- $\boldsymbol{W}_1 = \begin{pmatrix} \boldsymbol{X}_1 \otimes \boldsymbol{X}_2 & 0 \\ 0 & \boldsymbol{X}_1 \otimes \boldsymbol{X}_2 \end{pmatrix}$, $\boldsymbol{W}_2$ FFS
- $\boldsymbol{X}_1$ is a N_1xL_1 matrix with L_1 column vectors being an O_1x oversampled DFT vector of length N_1: $\boldsymbol{v}_l = \begin{bmatrix} 1 & e^{\frac{j2\pi l}{N_1 O_1}} & \ldots & e^{\frac{j2\pi (N_1-1) l}{N_1 O_1}} \end{bmatrix}^t$
- $\boldsymbol{X}_2$ is a N_2xL_2 matrix with L_2 column vectors being an O_2x oversampled DFT vector of length N_2: $\boldsymbol{v}_l = \begin{bmatrix} 1 & e^{\frac{j2\pi l}{N_2 O_2}} & \ldots & e^{\frac{j2\pi (N_2-1) l}{N_2 O_2}} \end{bmatrix}^t$
- N_1 and N_2 are the numbers of antenna ports per pol in 1st and 2nd dim.
- FFS whether to select different beams (e.g. different X1 or X2) for the two pols
- FFS column selection from KP applied to W_1

Class A proposal

- Rel.13 class A codebook configured with 5 RRC parameters:
  - N_1, N_2 = {1,2,3,4,8} where the valid candidates are (N_1, N_2) = (8,1), (2,2), (2,3), (3,2), (2,4), (4,2)
  - O_1, O_2 = {2,4,8}
    - For each (N_1, N_2), configurability of (O_1, O_2) is restricted to two possible fixed pairs
    - Exact values TBD by Fri, 10/09/2015
  - *Config* = {1, 2, 3, 4}
  - Note: For dimension with one port, oversampling factor and *Config* = {2, 3} do not apply
- Given the set of values of N_1,N_2,O_1,O_2:
  - $\mathbf{W}_1$ matrices with (L'_1,L'_2) = (4,2), (2,4) are constructed for N_1>N_2 and N_1<N_2, respectively
  - $\boldsymbol{W}_1 = \begin{pmatrix} \boldsymbol{X}_1^{m_1} \otimes \boldsymbol{X}_2^{m_2} & 0 \\ 0 & \boldsymbol{X}_1^{m_1} \otimes \boldsymbol{X}_2^{m_2} \end{pmatrix}$ where m_i is the index for $\boldsymbol{X_i}$
  - An associated codebook table is defined in terms of i'_2, i_{11} and i_{12} (refer to slide 5)
- Given the value of *Config*, a subset of codewords from the codebook table is selected as an active subset of values of i'_2, associated with one of the following 4 configurations: (see slide 5)
  - Config =1: (L_1,L_2) = (1,1) for rank 1-2
  - Config =2: (L_1,L_2) = (2,2) for rank 1-2 [square]
  - Config =3: (L_1,L_2) = (2,2) for rank 1-2 [non-adjacent 2D beams/checkerboard]
  - Config =4: (L_1,L_2) = (4,1), (1,4) for N_1>N_2 and N_1<N_2 respectively for rank 1-2
  - TBD rank 3-8

Class A proposal

- One selected value out of the active subset is reported by the second PMI i_2 in PUSCH reporting.

- Note: Configs 1-4 require the following $\mathbf{W}_1$ matrix construction:
  - $X_1^{m_1} \otimes X_2^{m_2}$ will have either 1 or 4 columns dependent upon the configuration:
    - *Config* = 1 : 1 column
    - *Config* = 2, 3, 4 : 4 columns

- The PMI feedback payload is adjusted based on *Config*
  - *Config* = 1 (compact i_2, no beam selection for 1 and 2 layers):
    - # of bits for i_{11} and i_{12} = ceil($\log_2(N_1O_1)$) + ceil($\log_2(N_2O_2)$)
    - # of bits for i_2 (per rank 1,2) = (2,2)
  - *Config* = 2, 3, 4 (following legacy):
    - # of bits for i_{11} and i_{12} = ceil($\log_2(N_1O_1/2)$)+ ceil($\log_2(N_2O_2/2)$)
    - # of bits for i_2 (per rank 1,2) = (4,4)
  - TBD rank 3-8

Class A: rank-1 CB

- The codebook is defined by the table below (with 32 CWs, $(L'_1, L'_2) = (4, 2)$). UE selects 4 or 16 CWs for the second PMI i_2 to be reported on PUSCH, based on *Config*.

i'_2	0	1	2	3
Precoder	$W^{(1)}_{s_1 i_{1,1}, s_2 i_{1,2}, 0}$	$W^{(1)}_{s_1 i_{1,1}, s_2 i_{1,2}, 1}$	$W^{(1)}_{s_1 i_{1,1}, s_2 i_{1,2}, 2}$	$W^{(1)}_{s_1 i_{1,1}, s_2 i_{1,2}, 3}$
i'_2	4	5	6	7
Precoder	$W^{(1)}_{s_1 i_{1,1}+1, s_2 i_{1,2}, 0}$	$W^{(1)}_{s_1 i_{1,1}+1, s_2 i_{1,2}, 1}$	$W^{(1)}_{s_1 i_{1,1}+1, s_2 i_{1,2}, 2}$	$W^{(1)}_{s_1 i_{1,1}+1, s_2 i_{1,2}, 3}$
i'_2	8	9	10	11
Precoder	$W^{(1)}_{s_1 i_{1,1}+2, s_2 i_{1,2}, 0}$	$W^{(1)}_{s_1 i_{1,1}+2, s_2 i_{1,2}, 1}$	$W^{(1)}_{s_1 i_{1,1}+2, s_2 i_{1,2}, 2}$	$W^{(1)}_{s_1 i_{1,1}+2, s_2 i_{1,2}, 3}$
i'_2	12	13	14	15
Precoder	$W^{(1)}_{s_1 i_{1,1}+3, s_2 i_{1,2}, 0}$	$W^{(1)}_{s_1 i_{1,1}+3, s_2 i_{1,2}, 1}$	$W^{(1)}_{s_1 i_{1,1}+3, s_2 i_{1,2}, 2}$	$W^{(1)}_{s_1 i_{1,1}+3, s_2 i_{1,2}, 3}$
i'_2	16 – 31			
Precoder	Entries 16-31 constructed with replacing the second subscript $s_2 i_{1,2}$ with $s_2 i_{1,2}+1$ in entries 0 – 15			

Oversampling factors o_d
Beam group spacing: s_d
First PMI: $i_{1,d}$

$$W^{(1)}_{m_1,m_2,n} = \frac{1}{\sqrt{Q}} \begin{bmatrix} v_{m_1} \otimes u_{m_2} \\ \varphi_n v_{m_1} \otimes u_{m_2} \end{bmatrix}$$

$$v_{m_1} = \begin{bmatrix} 1 & e^{j\frac{2\pi m_1}{o_1 N_1}} & \dots & e^{j\frac{2\pi m_1 (N_1-1)}{o_1 N_1}} \end{bmatrix}^t$$

$$u_{m_2} = \begin{bmatrix} 1 & e^{j\frac{2\pi m_2}{o_2 N_2}} & \dots & e^{j\frac{2\pi m_2 (N_2-1)}{o_2 N_2}} \end{bmatrix}^t$$

Config	Selected i'_2 indices	(s_1, s_2)
Config 1	0 – 3	(1,1)
Config 2	0 – 7, 16 – 23	(2,2)
Config 3	0-3, 8-11, 20-23, 28-31	(2,2)
Config 4	0 – 15	(2,2)

Codebook Subset Restriction

- Note: A 2D-beam corresponds to (l_1, l_2) in $\boldsymbol{X}_1 \otimes \boldsymbol{X}_2$
- Codebook subset restriction (CSR) is supported for FD-MIMO
  - CSR is configured via RRC signaling
  - A subset of 2D-beams (l_1, l_2) are forbidden, i.e. not allowed to be reported according to the CSR configuration
    - A forbidden 2D-beam is not allowed in reporting with any rank
  - Rank restriction is also supported
  - Number of PMI bits does not vary according to restricted subset
    - Note: Codebook subset restriction targets e.g. performance/capacity, as in Rel-8 to Rel-12

Background:
Class B alternatives (RAN1#82)

- Study the following aspects for CSI-process reporting class B, including but not limited to
  - Number of antenna ports *L* for CSI (e.g., 2, 4, 8)
  - Class B Alt-1:
    - Beam selection indicator (BI) definition, e.g. RSRP or CSI based, wideband vs. subband, short-term vs. long-term
    - BI bitwidth (related to K)
    - Support for rank>2 UE specific beamforming
    - UCI feedback mechanisms on PUCCH/PUSCH
  - Class B Alt-2:
    - Codebook for beam selection and co-phasing (either derived from legacy codebook(s) or codebook components, or newly designed)
      - Along with the associated PMI (e.g. assuming W = W2 in the newly designed or legacy codebook)
    - UCI feedback mechanisms on PUCCH/PUSCH
  - Class B Alt-3:
    - Codebook for beam selection and CSI
      - PMI contains the information of selected beam and the precoding matrix for the L-port within the selected beam
    - UCI feedback mechanisms on PUCCH/PUSCH
  - Class B Alt-4:
    - Measurement restriction mechanism; may be also applicable to Alt-1 to 3.
- Other aspects not precluded

Class B proposal

- Value K is configured to the UE where K≥1, representing K beams
  - K={1, 2, ..., 8} conditioned upon $N_1+...+N_K \leq N_{TOTAL}$
  - N_{TOTAL} is TBD
- For K>1
  - For each of the K beams, a value N_k={1, 2, 4, 8} is configured as one Rel.12 NZP CSI-RS resource
  - BI feedback is included in CSI report to select one out of K beams
  - For the selected beam k=k', CSI reporting based on legacy codebook for $N_{k'}$ ports
- One CSI process can be configured with multiple CSI-IM
  - Different CSI-RS resource can be associated with different CSI-IM

Class B proposal

- For K=1
  - A value N_1={1, 2, 4, 8} is configured as one Rel.12 NZP CSI-RS resource
    - eNodeB signals the number of ports N_1 via NZP CSI-RS resource configuration
  - CSI reporting with PMI-feedback-only based on W_2-only feedback for N_1 ports
    - Using all/components of W_2 in Rel.13 class A codebook configuration 4 (see slide 3)
      - DFT vectors are replaced by column vectors of identity matrix
  - In addition, legacy (Rel.12) CSI reporting is also supported with MR functionality

- For K=1, a new N_1-port codebook (where each different CSI-RS port is virtualized from different sets of antenna elements) is to be investigated and possibly specified in Rel.14

Other features

- MR (measurement restriction) is an independent feature (configurable ON/OFF)
  - For both channel and interference

- The maximum number X of CSI-IM is defined per UE across the maximum supported CSI processes.
  - X is the same for Class A and B
  - For Class A,
    - One CSI-IM per CSI process
    - Implies an increase in the max number of supported CSI processes if X>3
  - For Class B,
    - Multiple CSI-IM per CSI process is possible

3GPP TSG-RAN WG1#83 **R1-157203**
Anaheim, USA, 15th - 22nd November 2015

Source:	**Ericsson**
Title:	**Remaining Details of Codebook Subset Restriction**
Agenda Item:	**6.2.4.1**
Document for:	**Discussion and Decision**

1 Introduction

In RAN1#82bis, it was agreed that codebook subset restriction (CSR) is supported for FD-MIMO with Class A CSI reporting where [1]

- A 2D-beam corresponds to (l_1, l_2) in $\boldsymbol{X}_1 \otimes \boldsymbol{X}_2$
- CSR is configured via RRC signaling
- A subset of 2D-beams (l_1, l_2) are forbidden, i.e. not allowed to be reported according to the CSR configuration
    - A forbidden 2D-beam is not allowed in reporting with any rank
- Rank restriction is also supported
- Codebook Subset Restriction can be also applied to $\boldsymbol{W}_2$
- Number of PMI bits does not vary according to restricted subset
    - Note: Codebook subset restriction targets e.g. performance/capacity, as in Rel-8 to Rel-12

In [2], it was further agreed that

- For $\boldsymbol{W}_1$ CSR, a bitmap of $(N_1 O_1 N_2 O_2)$ bits indicates 2D-beams subset restriction (referred to as *Beam-Subset-Restriction* in the rest of the contribution),
- 8 additional bits bitmap indicates rank restriction
- An RRC parameter for CSR on Class A i_2 (i.e. $\boldsymbol{W}_2$) will be introduced.
    - Bitmap of all possible codewords per rank

In this contribution, we provide further details on the specification impact of supporting CSR for FD-MIMO. As the final details of the Class A codebook have only been agreed for rank 1, we make an assumption of the codebook for higher ranks, for the sake of this discussion, based on the contribution [4]. This codebook is also given in the appendix in Section 5.

2 Specification Impact for CSR

A 2D beam is identified by the parameters l_1 and l_2 and corresponds to two vectors for the first and second dimension respectively.

$$\mathbf{v}(l_1)=\begin{bmatrix}1 & e^{j\frac{2\pi l_1}{O_1 N_1}} & \cdots & e^{j\frac{2\pi l_1 (N_1-1)}{O_1 N_1}}\end{bmatrix}^T, \mathbf{u}(l_2)=\begin{bmatrix}1 & e^{j\frac{2\pi l_2}{O_2 N_2}} & \cdots & e^{j\frac{2\pi l_2 (N_2-1)}{O_2 N_2}}\end{bmatrix}^T$$

Since $l_1 = 0, \ldots, N_1 O_1 - 1$, $l_2 = 0, \ldots, N_2 O_2 - 1$, there are a total $N_1 O_1 N_2 O_2$ such 2D beams

2.1 Mapping between *Beam-Subset-Restriction* bits and 2D Beams

Let the bitmap for the *Beam-Subset-Restriction* RRC parameter be formed by the bit sequence $a_{S-1}, a_{S-2}, \cdots a_3, a_2, a_1, a_0$ where a_0 is the least significant bit (LSB), a_{S-1} is the most significant bit (MSB), and $S = N_1 O_1 N_2 O_2$. The index n of a bit a_n in the *Beam-Subset-Restriction* bitmap can be mapped to a 2D beam using the 'first dimension first' mapping scheme shown in Figure 1.

Now let (l'_1, l'_2) identify a forbidden 2D-beam (i.e., a 2D beam that is not allowed to be reported in any rank) corresponding to a DFT vector with index l'_1 in the first dimension and a DFT vector with index l'_2 in the second dimension. The indices l'_1 and l'_2 can be referred to as forbidden beam indices. If a bit in the *Beam-Subset-Restriction* bitmap indicates a forbidden 2D beam, then this bit corresponds to only one combination of a forbidden beam index l'_1 in the first dimension and a forbidden beam index l'_2 in the second dimension out of the $O_1N_1O_2N_2$ possible combinations of the first beam index l_1 and the second beam index l_2 .

If we assume a 'first dimension first' mapping scheme, then the bit a_n forbids a 2D beam with indices

$$l'_1 = n - N_1O_1\left\lfloor\frac{n}{N_1O_1}\right\rfloor$$

$$l'_2 = \left\lfloor\frac{n}{N_1O_1}\right\rfloor.$$

Equivalently, n can be calculated from l'_1 and l'_2 with $n = l'_1 + N_1O_1l'_2$. An example of the first dimension first mapping scheme with $(N_1, N_2) = (2,2)$ and $(O_1, O_2) = (4,4)$ is illustrated in Figure 2.

Proposal 1: The n^{th} bit a_n of the *Beam-Subset-Restriction* bitmap is used to forbid a 2D beam with indices (l'_1, l'_2), where $l'_1 = n - N_1O_1\left\lfloor\frac{n}{N_1O_1}\right\rfloor$ and $l'_2 = \left\lfloor\frac{n}{N_1O_1}\right\rfloor$.

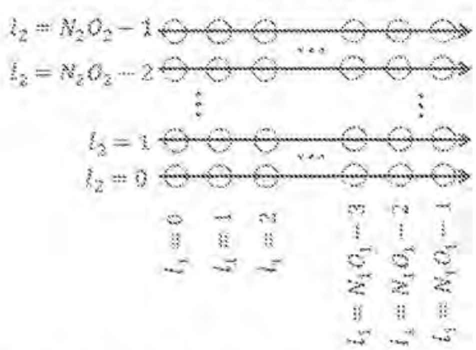

Figure 1. A 'first dimension first' mapping between *Beam-Subset-Restriction* bits and 2D beams.

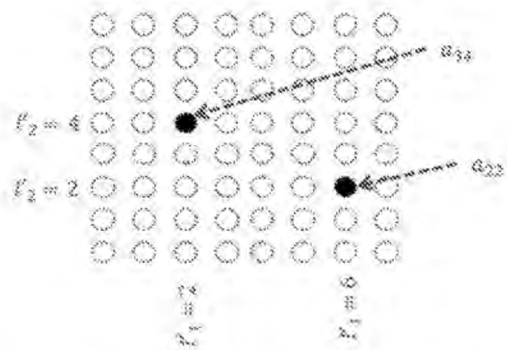

Figure 2. Example of 'first dimension first' mapping.

2.2 Beam Restriction across Ranks

Considering the rank 1 Class A codebook agreed in [1], a given rank-1 codeword $W^{(1)}_{m_1,m_2,n}$ as defined in **Error! Reference source not found.** of the Appendix is forbidden (i.e., not allowed to be reported), if $m_1 = l'_1$ and $m_2 = l'_2$ simultaneously, where the range of (m_1, m_2) are determined by the value of *Config* (see [1] for details) and (l'_1, l'_2) represents the forbidden beam indices of any 2D beam that is not allowed to be reported (as signaled by the *Beam-Subset-Restriction* bitmap).

For the Class A codebooks of ranks 2, 3, and 4 described in Sections 5.2, 5.3, and 5.4, respectively, a given codeword (which, depending on the rank, can be defined by **Error! Reference source not found.**), **Error! Reference source not found.**), **Error! Reference source not found.**, or **Error! Reference source not found.** in the Appendix) is forbidden (i.e., not allowed to be reported) if **either or both** of the following two conditions are met

Condition 1: $m_1 = l'_1$ and $m_2 = l'_2$
Condition 2: $m'_1 = l'_1$ and $m'_2 = l'_2$

where possible values of (m_1, m_2) and (m'_1, m'_2) are determined by the value of *Config* (see [3]-[4] for details). Furthermore, (l'_1, l'_2) represents any 2D beam that is not allowed to be reported (as signaled by the *Beam-Subset-Restriction* bitmap).

For the rank 5-8 Class A codebooks of Section 5.5, the rules for applying beam restriction has to be formulated slightly differently since codewords for ranks 5-8 are indexed with $i_{1,1}$ and $i_{1,2}$ as opposed to the parameters m_1, m_2, m'_1, m'_2. For the rank 5-8 Class A codebooks, a given rank 5-8 codeword is forbidden (i.e. not allowed to be reported) if the codeword contains at least one forbidden 2D beam (as defined jointly by l'_1 and l'_2). This happens if at least one of the conditions given in Table 1 is met. In Table 1, the $\delta_{i,j}$ values are those from the rank 5-8 codebooks which are determined by the parameters N_1, N_2, and the configuration associated with the codebook (see [4] for details).

The $i_{1,1}$ and $i_{1,2}$ indices are the PMI indices corresponding to the first and second dimensions. The conditions in each column of the table are checked a column at a time according to the rank (denoted by r). Conditions 1-3 apply to codewords with ranks 5, 6, 7, or 8, while Condition 4 only applies to codewords with ranks 7 or 8. For at least one applicable column (i.e., condition), if forbidden beam index l'_1 is equal to the table entry on the first row of the column, and if forbidden beam index l'_2 is simultaneously equal to the table entry on the second row of the column, then codeword $W^{(r)}_{i_{1,1},i_{1,2}}$ is forbidden (i.e., not allowed to be reported).

Table 1: Rank 5-8 Codeword Restriction

	Condition 1	Condition 2	Condition 3	Condition 4
Rank	5,6,7,8	5,6,7,8	5,6,7,8	7,8
l'_1	$s_1 i_{1,1}$	$s_1 i_{1,1} + \delta_{1,1}$	$s_1 i_{1,1} + \delta_{1,2}$	$s_1 i_{1,1} + \delta_{1,3}$
l'_2	$s_2 i_{1,2}$	$s_2 i_{1,2} + \delta_{2,1}$	$s_2 i_{1,2} + \delta_{2,2}$	$s_2 i_{1,2} + \delta_{2,3}$

Proposal 2: Specify the following rules for applying beam restriction of a forbidden 2D beam (l'_1, l'_2) across ranks:

- **For rank 1-4:** A codeword indicated by the parameters m_1, m_2 or parameters m_1, m_2, m'_1, m'_2 shall not be reported if either or both of these conditions are met:
    - Condition 1: $m_1 = l'_1$ and $m_2 = l'_2$ simultaneously
    - Condition 2: $m'_1 = l'_1$ and $m'_2 = l'_2$ simultaneously
- **For rank 5-8:** A codeword shall not be reported if at least one of the conditions given in Table 1 are met by both rows corresponding to l'_1 and l'_2 simultaneously.

2.3 CSR Configuration Conflict Cases

When a UE signaled with more than one of the CSR restrictions (i.e. *Beam-Subset-Restriction, CLASS A i2 restriction and* Rank Restriction) , different codewords may be forbidden by the different bitmaps. Some rules are needed in terms of which restriction bitmap has the higher priority in case of conflicts, e.g. a codeword is allowed in one restriction bitmap but not allowed in another restriction bitmap(s). The more straightforward rule is to not allow a codeword belonging to a particular rank to be reported if the codeword is forbidden by any one of the multiple restriction bitmaps.

Proposal 3: A codeword belonging to a particular rank is not allowed to be reported if the codeword is forbidden by any one of the multiple CSR restriction bitmaps.

3 Conclusion

In this contribution, we provide further details on the specification impact of supporting CSR for FD-MIMO based on the CSR parameters agreed in RAN1#82bis. We make the following proposals:

Proposal 1: The n^{th} bit a_n of the *Beam-Subset-Restriction* bitmap is used to forbid a 2D beam with indices (l'_1, l'_2), where $l'_1 = n - N_1O_1\left\lfloor\frac{n}{N_1O_1}\right\rfloor$ and $l'_2 = \left\lfloor\frac{n}{N_1O_1}\right\rfloor$.

Proposal 2: Specify the following rules for applying beam restriction of a forbidden 2D beam (l'_1, l'_2) across ranks:

- **For rank 1-4:** A codeword indicated by the parameters m_1, m_2 or parameters m_1, m_2, m'_1, m'_2 not be reported if either or both of these conditions are met:
  - Condition 1: $m_1 = l'_1$ and $m_2 = l'_2$ simultaneously
  - Condition 2: $m'_1 = l'_1$ and $m'_2 = l'_2$ simultaneously
- **For rank 5-8:** A codeword shall not be reported if at least one of the conditions given in Table 1 are met by both rows corresponding to l'_1 and l'_2 simultaneously

Table 1: Rank 5-8 Codeword Restriction

	Condition 1	Condition 2	Condition 3	Condition 4
Rank	5,6,7,8	5,6,7,8	5,6,7,8	7,8
$l'_1 =$	$s_1i_{1,1}$	$s_1i_{1,1} + \delta_{1,1}$	$s_1i_{1,1} + \delta_{1,2}$	$s_1i_{1,1} + \delta_{1,3}$
$l'_2 =$	$s_2i_{1,2}$	$s_2i_{1,2} + \delta_{2,1}$	$s_2i_{1,2} + \delta_{2,2}$	$s_2i_{1,2} + \delta_{2,3}$

Proposal 3: A codeword belonging to a particular rank is not allowed to be reported if the codeword is forbidden by any one of the multiple CSR restriction bitmaps.

4 References

[1] R1-156217, "WF on class A and class B CSI reporting for Rel.13 EB/FD-MIMO", AT&T, Beijing Xinwei Telecom Tech., CATR, CATT, CHTTL, CMCC, Deutsche Telekom, Ericsson, ETRI, Huawei, HiSilicon, ITRI, Kathrein-Werke KG, KDDI, KT Corporation, Nokia Networks, NTT DOCOMO, Samsung, Sony Corporation, 3GPP TSG-RAN WG1#82bis, Malmö, Sweden, October 5-9, 2015.

[2] RAN1 Chairman's Notes, 3GPP TSG-RAN WG1#82bis, Malmö, Sweden, October 5-9, 2015.

[3] R1-156335, "Joint Proposal on Rank 2 Codebook for Class A CSI Reporting", Samsung, Ericsson, 3GPP TSG-RAN WG1#82bis, Malmö, Sweden, October 5-9, 2015.

[4] R1-156390, "Joint proposal on rank 3-8 codebook," Samsung, Ericsson, NTT DOCOMO, CATT, 3GPP TSG-RAN WG1 #83, Anaheim, USA, November 16-20, 2015.

5 Appendix: Class A Codebook Agreements and Proposals

5.1 Rank-1 Class A Codebook

In [1], a class A codebook for rank-1 was agreed. As per the agreement, a selected rank-1 codeword $W^{(1)}_{m_1,m_2,n}$ can be represented as

$$W^{(1)}_{m_1,m_2,n} = \frac{1}{\sqrt{Q}} \begin{bmatrix} v_{m_1} \otimes u_{m_2} \\ \varphi_n v_{m_1} \otimes u_{m_2} \end{bmatrix}, \quad (1)$$

wherein $\varphi_n = e^{j\pi n/2}$ and $Q \in \{8, 12, 16\}$. In **Error! Reference source not found.**), the single layer of data is transmitted on the 2-dimensional beam involving the m_1^{th} beam in the first dimension and the m_2^{th} beam in the second dimension where

$$v_{m_1} = \begin{bmatrix} 1 & e^{j\frac{2\pi m_1}{O_1 N_1}} & \dots & e^{j\frac{2\pi m_1(N_1-1)}{O_1 N_1}} \end{bmatrix}^t. \quad (2)$$

$$u_{m_2} = \begin{bmatrix} 1 & e^{j\frac{2\pi m_2}{O_2 N_2}} & \dots & e^{j\frac{2\pi m_2(N_2-1)}{O_2 N_2}} \end{bmatrix}^t. \quad (3)$$

Further details of the agreed class A codebook rank-1 codebook can be found in [1].

5.2 Rank-2 Class A Codebook

A class A codebook for rank-2 is proposed in [3]. In [3], a selected rank-2 codeword $W^{(2)}_{m_1,m_2,m_1',m_2',n}$ can be represented as

$$W^{(2)}_{m_1,m_2,m_1',m_2',n} = \frac{1}{\sqrt{2Q}} \begin{bmatrix} v_{m_1} \otimes u_{m_2} & v_{m_1'} \otimes u_{m_2'} \\ \varphi_n v_{m_1} \otimes u_{m_2} & -\varphi_n v_{m_1'} \otimes u_{m_2'} \end{bmatrix}. \quad (4)$$

In **Error! Reference source not found.**, the first layer of data is transmitted on the 2-dimensional beam involving the m_1^{th} beam in the first dimension and the m_2^{th} beam in the second dimension; the second layer of data is transmitted on the 2-dimensional beam involving the $(m_1')^{th}$ beam in the first dimension and the $(m_2')^{th}$ beam in the second dimension. Further details of the proposed class A codebook for rank-2 can be found in [3].

5.3 Rank-3 Class A Codebook

A joint proposal for rank-3 class A codebook is presented in [4]. A selected rank-3 codeword can either be represented by $W^{(3)}_{m_1,m_1',m_2,m_2'}$ or $\widetilde{W}^{(3)}_{m_1,m_1',m_2,m_2'}$, where

$$W^{(3)}_{m_1,m_1',m_2,m_2'} = \frac{1}{\sqrt{3Q}} \begin{bmatrix} v_{m_1} \otimes u_{m_2} & v_{m_1'} \otimes u_{m_2'} & v_{m_1'} \otimes u_{m_2'} \\ v_{m_1} \otimes u_{m_2} & -v_{m_1'} \otimes u_{m_2'} & -v_{m_1'} \otimes u_{m_2'} \end{bmatrix}, \quad (5)$$

$$\widetilde{W}^{(3)}_{m_1,m_1',m_2,m_2'}=\frac{1}{\sqrt{3Q}}\begin{bmatrix} v_{m_1}\otimes u_{m_2} & v_{m_1'}\otimes u_{m_2} & v_{m_1'}\otimes u_{m_2'} \\ v_{m_1}\otimes u_{m_2} & v_{m_1'}\otimes u_{m_2'} & -v_{m_1'}\otimes u_{m_2'} \end{bmatrix}. \quad \textbf{(6)}$$

Further details of the proposed class A codebook for rank-3 can be found in [4].

5.4 Rank-4 Class A Codebook

A class A codebook for rank-4 is proposed in [4]. In [4], a selected rank-4 codeword $W^{(4)}_{m_1,m_1',m_2,m_2',n}$ can be represented as

$$W^{(4)}_{m_1,m_1',m_2,m_2',n}=\frac{1}{\sqrt{4Q}}\begin{bmatrix} v_{m_1}\otimes u_{m_2} & v_{m_1'}\otimes u_{m_2'} & v_{m_1}\otimes u_{m_2} & v_{m_1'}\otimes u_{m_2'} \\ \varphi_n v_{m_1}\otimes u_{m_2} & \varphi_n v_{m_1'}\otimes u_{m_2'} & -\varphi_n v_{m_1}\otimes u_{m_2} & -\varphi_n v_{m_1'}\otimes u_{m_2'} \end{bmatrix}. \quad \textbf{(7)}$$

Further details of the proposed class A codebook for rank-4 can be found in [4].

5.5 Class A Codebooks for Ranks 5-8

Class A codebooks for ranks 5-8 are proposed in [4]. A precoding matrix codeword for rank r (r = 5,6,7,8) is denoted as $W^{(r)}_{i_{1,1},i_{1,2}}$. The precoding matrix codewords $W^{(r)}_{i_{1,1},i_{1,2}}$, r = 5,6,7,8 are then defined as

$$W^{(5)}_{i_{1,1},i_{1,2}}=\frac{1}{\sqrt{5Q}}\begin{bmatrix} v_{s_1i_{1,1}}\otimes u_{s_2i_{1,2}} & v_{s_1i_{1,1}}\otimes u_{s_2i_{1,2}} & v_{s_1i_{1,1}+\delta_{1,1}}\otimes u_{s_2i_{1,2}+\delta_{2,1}} & v_{s_1i_{1,1}+\delta_{1,1}}\otimes u_{s_2i_{1,2}+\delta_{2,1}} & v_{s_1i_{1,1}+\delta_{1,2}}\otimes u_{s_2i_{1,2}+\delta_{2,2}} \\ v_{s_1i_{1,1}}\otimes u_{s_2i_{1,2}} & -v_{s_1i_{1,1}}\otimes u_{s_2i_{1,2}} & v_{s_1i_{1,1}+\delta_{1,1}}\otimes u_{s_2i_{1,2}+\delta_{2,1}} & -v_{s_1i_{1,1}+\delta_{1,1}}\otimes u_{s_2i_{1,2}+\delta_{2,1}} & v_{s_1i_{1,1}+\delta_{1,2}}\otimes u_{s_2i_{1,2}+\delta_{2,2}} \end{bmatrix} \quad \textbf{(8)}$$

$$W^{(6)}_{i_{1,1},i_{1,2}}=\frac{1}{\sqrt{6Q}}\begin{bmatrix} v_{s_1i_{1,1}}\otimes u_{s_2i_{1,2}} & v_{s_1i_{1,1}}\otimes u_{s_2i_{1,2}} & v_{s_1i_{1,1}+\delta_{1,1}}\otimes u_{s_2i_{1,2}+\delta_{2,1}} & v_{s_1i_{1,1}+\delta_{1,1}}\otimes u_{s_2i_{1,2}+\delta_{2,1}} & v_{s_1i_{1,1}+\delta_{1,2}}\otimes u_{s_2i_{1,2}+\delta_{2,2}} & v_{s_1i_{1,1}+\delta_{1,2}}\otimes u_{s_2i_{1,2}+\delta_{2,2}} \\ v_{s_1i_{1,1}}\otimes u_{s_2i_{1,2}} & -v_{s_1i_{1,1}}\otimes u_{s_2i_{1,2}} & v_{s_1i_{1,1}+\delta_{1,1}}\otimes u_{s_2i_{1,2}+\delta_{2,1}} & -v_{s_1i_{1,1}+\delta_{1,1}}\otimes u_{s_2i_{1,2}+\delta_{2,1}} & v_{s_1i_{1,1}+\delta_{1,2}}\otimes u_{s_2i_{1,2}+\delta_{2,2}} & -v_{s_1i_{1,1}+\delta_{1,2}}\otimes u_{s_2i_{1,2}+\delta_{2,2}} \end{bmatrix} \quad \textbf{(9)}$$

$$W^{(7)}_{i_{1,1},i_{1,2}}=\frac{1}{\sqrt{7Q}}\begin{bmatrix} v_{s_1i_{1,1}}\otimes u_{s_2i_{1,2}} & v_{s_1i_{1,1}}\otimes u_{s_2i_{1,2}} & v_{s_1i_{1,1}+\delta_{1,1}}\otimes u_{s_2i_{1,2}+\delta_{2,1}} & v_{s_1i_{1,1}+\delta_{1,1}}\otimes u_{s_2i_{1,2}+\delta_{2,1}} & v_{s_1i_{1,1}+\delta_{1,2}}\otimes u_{s_2i_{1,2}+\delta_{2,2}} & v_{s_1i_{1,1}+\delta_{1,2}}\otimes u_{s_2i_{1,2}+\delta_{2,2}} & v_{s_1i_{1,1}+\delta_{1,3}}\otimes u_{s_2i_{1,2}+\delta_{2,3}} \\ v_{s_1i_{1,1}}\otimes u_{s_2i_{1,2}} & -v_{s_1i_{1,1}}\otimes u_{s_2i_{1,2}} & v_{s_1i_{1,1}+\delta_{1,1}}\otimes u_{s_2i_{1,2}+\delta_{2,1}} & -v_{s_1i_{1,1}+\delta_{1,1}}\otimes u_{s_2i_{1,2}+\delta_{2,1}} & v_{s_1i_{1,1}+\delta_{1,2}}\otimes u_{s_2i_{1,2}+\delta_{2,2}} & -v_{s_1i_{1,1}+\delta_{1,2}}\otimes u_{s_2i_{1,2}+\delta_{2,2}} & v_{s_1i_{1,1}+\delta_{1,3}}\otimes u_{s_2i_{1,2}+\delta_{2,3}} \end{bmatrix} \quad \textbf{(10)}$$

$$W^{(8)}_{i_{1,1},i_{1,2}}=\frac{1}{\sqrt{8Q}}\begin{bmatrix} v_{s_1i_{1,1}}\otimes u_{s_2i_{1,2}} & v_{s_1i_{1,1}}\otimes u_{s_2i_{1,2}} & v_{s_1i_{1,1}+\delta_{1,1}}\otimes u_{s_2i_{1,2}+\delta_{2,1}} & v_{s_1i_{1,1}+\delta_{1,1}}\otimes u_{s_2i_{1,2}+\delta_{2,1}} & v_{s_1i_{1,1}+\delta_{1,2}}\otimes u_{s_2i_{1,2}+\delta_{2,2}} & v_{s_1i_{1,1}+\delta_{1,2}}\otimes u_{s_2i_{1,2}+\delta_{2,2}} & v_{s_1i_{1,1}+\delta_{1,3}}\otimes u_{s_2i_{1,2}+\delta_{2,3}} & v_{s_1i_{1,1}+\delta_{1,3}}\otimes u_{s_2i_{1,2}+\delta_{2,3}} \\ v_{s_1i_{1,1}}\otimes u_{s_2i_{1,2}} & -v_{s_1i_{1,1}}\otimes u_{s_2i_{1,2}} & v_{s_1i_{1,1}+\delta_{1,1}}\otimes u_{s_2i_{1,2}+\delta_{2,1}} & -v_{s_1i_{1,1}+\delta_{1,1}}\otimes u_{s_2i_{1,2}+\delta_{2,1}} & v_{s_1i_{1,1}+\delta_{1,2}}\otimes u_{s_2i_{1,2}+\delta_{2,2}} & -v_{s_1i_{1,1}+\delta_{1,2}}\otimes u_{s_2i_{1,2}+\delta_{2,2}} & v_{s_1i_{1,1}+\delta_{1,3}}\otimes u_{s_2i_{1,2}+\delta_{2,3}} & -v_{s_1i_{1,1}+\delta_{1,3}}\otimes u_{s_2i_{1,2}+\delta_{2,3}} \end{bmatrix} \quad \textbf{(11)}$$

In **Error! Reference source not found.-Error! Reference source not found.**, the values of $\delta_{1,1}$, $\delta_{1,2}$, $\delta_{1,3}$, $\delta_{2,1}$, $\delta_{2,2}$, $\delta_{2,3}$ are determined by the parameters N_1, N_2, and the configuration associated with the codebook. Further details of these values can be found in [4].

Electronic Patent Application Fee Transmittal

Application Number:	
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Title of Invention:	Codebook Subset Restriction Signaling
First Named Inventor/Applicant Name:	Sebastian Faxér
Filer:	Justin J. Leonard/Katya Fox
Attorney Docket Number:	4015-9595 / P45698-US2

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International Application Number:	PCT/SE2016/050009
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First Named Inventor/Applicant Name:	Sebastian Faxér
Customer Number:	24112
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EFS ID:	21202379
Application Number:	62103101
International Application Number:	
Confirmation Number:	9403
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First Named Inventor/Applicant Name:	Sebastian Faxér
Customer Number:	24112
Filer:	Justin J. Leonard/Kristi Dunshee
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CODEBOOK SUBSET RESTRICTION SIGNALING

BACKGROUND

[0001] The use of multiple antennas at the transmitter and/or the receiver of a wireless communication system can significantly boost the capacity and coverage of a wireless communication system. Such MIMO systems can exploit the spatial dimension of the communication channel. For example, several information-carrying signals can be sent in parallel using the transmit antennas and still be separated by signal processing at the receiver. By adapting the transmission to the current channel conditions, significant additional gains can be achieved. One form of adaptation is to dynamically, from one TTI to another, adjust the number of simultaneously transmitted information streams carrying signals to what the channel can support. This is commonly referred to as (transmission) rank adaptation. Precoding is another form of adaptation where the phases and amplitudes of the aforementioned signals are adjusted to better fit the current channel properties. The signals form a vector-valued signal and the adjustment can be thought of as multiplication by a precoder matrix. A common approach is to select the precoder matrix from a finite and indexed set, a so-called codebook. Such codebook-based precoding is an integral part of the LTE standard, as well as in many other wireless communication standards.

[0002] Codebook based precoding can be regarded as a form of channel quantization. A typical approach (c.f. LTE and MIMO HSDPA) is to let the receiver recommend a suitable precoder matrix to the transmitter by signaling the precoder matrix indicator (PMI) over a feedback link. To limit signaling overhead, it is generally important to keep the codebook size as small as possible if the feedback link has a limited capacity. This however needs to be balanced against the performance impact since with a larger codebook it is possible to better match the current channel conditions.

[0003] For example, in the LTE downlink, the UE reports the PMI to the eNodeB either periodically on PUCCH or aperiodic on the PUSCH. The former is a rather narrow bit pipe where CSI feedback is reported in a semi-statically configured and periodic fashion. On the other hand, reporting on PUSCH is dynamically triggered as part of the uplink grant. Thus, the eNodeB can schedule CSI transmissions in a dynamic fashion. In contrast to the PUCCH where the number of physical bits is currently limited to 20, the reports on PUSCH can be considerably larger. Thus, for feedback on PUCCH a small codebook size is desirable to keep the signaling overhead down. However, for feedback on PUSCH a larger codebook size is desirable to increase performance, since the capacity on the feedback channel is not as limited in this case.

[0004] The desired size of the codebook may also depend on the transmission scheme used. For example, a codebook used in MU-MIMO operation could benefit more from having a larger number of elements than a codebook used in SU-MIMO operation. In the former case, a large spatial resolution is important to allow for sufficient UE separation.

[0005] A convenient way to support different codebook sizes is to use a large codebook with many elements by default and apply *codebook subset restriction* in the scenarios where a smaller codebook is beneficial. With codebook subset restriction, a subset of the precoders in the codebook is restricted so that the UE has a smaller set of possible precoders to choose from. This effectively reduces the size of the codebook implying that the search for the best PMI can be done on the smaller unrestricted set of precoders, thereby also reducing the UE computational requirements for this particular search. Typically, the eNodeB would signal the codebook subset restriction to the UE by means of a bitmap in an a dedicated message part of the AntennaInfo information element (see the RRC specification, TS 36.331), one bit for each precoder in the codebook, where a 1 would indicate that the precoder is restricted (meaning that the UE is not allowed to choose and report said precoder). Thus, for a codebook with *N* elements, a bitmap of length *N* would be used to signal the codebook subset restriction. This allows for full flexibility for the eNodeB to restrict every possible subset of the codebook. There are thus 2^N possible codebook subset restriction configurations.For large antenna arrays with many antenna elements, the effective beams become narrow and a codebook containing many precoders is required for the intended coverage area. Furthermore, for two-dimensional antenna arrays, the codebook size increases quadratically since the precoders in the codebook need to span two dimensions, typically the horizontal and vertical domain. Thus, the codebook size (i.e. the total number of possible precoding matrices W) can be very large. Signaling a codebook subset restriction in the conventional way by means of a bitmap with one bit for every precoder can thus impose a large overhead, especially if the codebook subset restriction (CSR) is frequently updated or if there are many users served by the cell which each has to receive the CSR.

SUMMARY

[0006] One or more embodiments herein advantageously lower the signaling overhead imposed by transmitting a codebook subset restriction, while still allowing for flexibility in configuring different codebook subset restrictions.

[0007] Embodiments herein therefore generally include methods to reduce the number of bits required for signaling a codebook subset restriction configuration to a UE. The methods in one or more of these embodiments do so by:

- Utilizing an explicit or implicit assumption about which sets of precoders are more likely to be restricted, and/or
- Associating a group of precoders with a single codebook subset restriction bit.

DETAILED DESCRIPTION

[0008] According to the flowchart of Figure 1, a network node in a wireless communication network (e.g., an eNB in the network) signals a codebook subset restriction (CSR) configuration to a wireless communication device (e.g., a UE). The device then sends a channel state information (CSI) report back to the network. This CSI report suggests which of different possible precoders in a codebook the network should use for transmitting to the deivce, but the CSI report is restricted in the sense that there is a subset of precoders that cannot be reported by the device; that is, all precoders in the codebook cannot be selected and reported by the device. This restriction is defined by the signaled CSR configuration.

[0009] In more detail, for a precoder codebook X, consisting of N precoders, there are 2^N possible codebook subset restriction configurations since each precoder can individually either be allowed or restricted (a restricted configuration is not allowed to be used). Each configuration can be represented by a bitmap of N bits, where each bit corresponds to a certain precoder and the value of the bit then indicates whether the precoder is restricted or not. If each of the 2^N configurations is equiprobable and independent, this is the optimal representation of a codebook subset restriction configuration with respect to the expected length (in bits) of the representation and it provides full flexibility.

[0010] However, embodiments herein recognize that, if certain configurations are more likely to be used than others, and/or if the restriction of one precoder is highly correlated to the restriction of another precoder, then this signaling leads to unnecessarily high signaling overhead. One or more embodiments herein include methods to reduce this signaling overhead; that is, reduce the number of bits required for signaling a codebook subset restriction configuration to a wireless communication device from the network. In some embodiments, for example, the methods utilize an implicit assumption about which sets of precoders are more likely to be restricted or which sets of precoders are likely to be jointly restricted.

Method in A Network Node

[0011] According to one embodiment shown in Figure 2, for example, a method is implemented by a network node (e.g., a base station) for signaling to a wireless communication device which precoders in a codebook are restricted from being used. For each of one or more groups of precoders in the codebook, the method includes identifying one or more reference configurations for the group (Block 110). Each reference configuration is one of different possible configurations that restrict different subgroups of precoders in the group from being used. One of the reference configurations for a group may be for instance whichever one of the different possible configurations has the maximum probability of being signaled, e.g., as predicted or estimated based on empirical observations or implicit assumptions. Regardless, the method further includes identifying, from the different possible configurations for the group, the actual configuration to be signaled for the group (Block 120).

[0012] The method also includes generating signaling to indicate the actual configuration for the group (Block 130). This entails generating the signaling as a bit pattern whose length depends on (i) whether the actual configuration matches one of the one or more reference configurations; and/or (ii) which reference configuration the actual configuration matches. In some embodiments, for example, when the actual configuration matches any reference configuration, the bit pattern's length is shorter than when the actual configuration does not match any reference configuration. In other embodiments, when the actual configuration matches a particular one of multiple reference configurations, the bit pattern's length is shorter than when the actual configuration matches a different one of the reference configurations. Regardless, this process (Blocks 110-130) is repeated for each of one or more groups of precoders in the codebook (Blocks 100, 140, and 150). Finally, the method includes sending the generated signaling to the wireless communication device (Block 160).

[0013] This approach may in some sense be viewed as a sort of compression algorithm for CSR signaling. Indeed, the approach advantageously reduces the signaling overhead when, over the course of a given time period, the overhead savings realized by signaling bit patterns with relatively shorter lengths outweighs the overhead costs imposed by signaling bit patterns with relatively longer lengths. Depending on the relative lengths of the bit patterns, then, the approach may for instance reduce signaling overhead when the one or more reference configurations (or particular ones of the one or more reference configurations) are signaled more often than not.

[0014] In at least some embodiments, therefore, a reference configuration has a higher likelihood or probability of being signaled than any other possible configurations that are not reference configurations. For example, the one or more reference configurations for a group may include whichever one(s) of the different possible configurations for the group have the highest probability of being signaled. Different reference configurations that have different probabilities of being signaled may be represented with bit patterns of different lengths, where reference configurations with higher probabilities are represented with bit patterns of shorter lengths. That is, certain configurations that are deemed more probable may be represented with a fewer number of bits, while other configurations, that are deemed less probable to be used, may be represented with a larger number of bits.

[0015] In some embodiments, the one or more reference configurations may be predefined to be particular one(s) of the possible configurations, e.g., based on an (implicit) assumption that the particular configuration(s) have the highest probability of being signaled. For example, an implicit assumption is made on how the network is likely to be configured. Hence, here certain configurations are considered more likely than others but there are no actual probability values estimated for the different configurations.

[0016] In other embodiments, though, the network node determines signaling probabilities of different configurations, e.g., based on empirical observations and compares those probabilities to identify the configuration(s) with the highest probability. In one embodiment for example signaling probabilities are estimated through logging of network data. Hence, here it may be possible to estimate actual probabilities for the different configurations. In general, therefore, the knowledge on "how likely" a certain configuration is may be obtained in many ways.

[0017] In some embodiments, only a single reference configuration is defined for a group. In this case, the signaling is generated as a short bit pattern when the actual configuration matches the reference configuration and as a long bit pattern when the actual configuration does not match the reference configuration. Different long bit patterns in this regard are respectively defined for signaling different configurations (other than the reference configuration, for which the short bit pattern is defined for signaling). A long bit pattern of course has more bits than a short bit pattern (e.g., N bits vs. 1 bit).

[0018] In other embodiments, multiple reference configurations are defined for a group. In this case, the signaling may be generated as bit patterns that have different lengths when the actual configuration matches different reference configurations. These lengths may correspond to how likely it is that the reference configurations will be signaled. The bit pattern's length may be shortest when the actual configuration matches a particular one of the reference configurations (e.g., the one with the maximum probability of being signaled), may be next shortest when the actual configuration matches a different reference configuration (e.g., the one with the next highest signaling probability), and may be longest when the actual configuration does not match any of the reference configurations.

[0019] In some embodiments, bit patterns signaling non-reference configurations are encoded as a combination of a so-called "non-reference bit pattern" and a "bitmap." The non-reference bit pattern is defined for signaling that the actual configuration for the group does not match any reference configuration for the group. The non-reference bit pattern may for instance be the complement of a bit pattern defined for signaling a reference configuration. For example, when only a single reference configuration is defined for a group, the bit pattern signaling that reference configuration may simply be a single bit with a value of "1", whereas the non-reference bit pattern may be a single bit with a value of "0". Regardless, the bitmap portion of the bit pattern comprises different bits respectively dedicated to indicating whether different precoders in the group are restricted from being used.

[0020] In at least some embodiments, the method is performed for only one group. This single group in one embodiment includes all precoders in the codebook.

[0021] In another embodiment, of course, the single group includes only a portion of the precoders in the codebook, such that the signaling approach is adopted for only this portion, while other signaling approaches (e.g., the conventional bitmap) is adopted for other portions.

[0022] In other embodiments, the method is performed for multiple different groups that respectively include different portions of the precoders in the codebook. In one such embodiment, the signaling indicates the actual configurations for the groups in a defined order. In one embodiment, the one or more reference configurations for any given group includes the actual configuration, if any, signaled immediately before that of the given group (according to the defined order).

[0023] Consider a simple example with an arbitrary codebook of size N, where the single group includes all N precoders. A certain configuration out of the 2^N possible codebook subset restriction configurations for the single group is deemed more probable. This configuration is represented by a single bit, '1'. The other $2^N - 1$ configurations are represented by a '0', followed by a bitmap of size N. One of the configurations is then represented by 1 bit, while the other configurations are represented by $N + 1$ bits. Since the configuration represented by one bit is more frequently signaled, according to the assumption, the average number of bits required to convey the codebook subset restriction may be much less than N.

[0024] However, if the assumption that one of the possible codebook subset restriction configurations was more likely than the others was incorrect for the actual usage of codebook subset restriction configurations, the average number of bits required to convey a codebook subset restriction to a UE may be larger than N bits. One or more embodiments herein therefore aim to choose the representations of the 2^N configurations well. Various methods may represent the 2^N configurations differently depending on which sets of precoders are more likely to be restricted.

[0025] Consider for example embodiments where the codebook is defined for a multi-dimensional (e.g., two-dimensional) antenna array. Such antenna arrays may be (partly) described by the number of antenna columns corresponding to the horizontal dimension M_h, the number of antenna rows corresponding to the vertical dimension M_v and the number of dimensions corresponding to different polarizations M_p The total number of antennas is thus $M = M_h M_v M_p$. It should be pointed out that the concept of an antenna is non-limiting in the sense that it can refer to any virtualization (e.g., linear mapping) of the physical antenna elements. For example, pairs of physical sub-elements could be fed the same signal, and hence share the same virtualized antenna port.

[0026] An example of a 4x4 array with cross-polarized antenna elements is illustrated in Figure 3. Specifically, Figure 3 shows a two-dimensional antenna array of cross-polarized antenna elements ($M_P = 2$), with $M_h = 4$ horizontal antenna elements and $M_v = 4$ vertical antenna elements, assuming one antenna element corresponds to one antenna port.

[0027] Precoding may be interpreted as multiplying the signal with different beamforming weights for each antenna prior to transmission. A typical approach is to tailor the precoder to the antenna form factor, i.e. taking into account M_h, M_v and M_p when designing the precoder codebook.

[0028] According to some embodiments, a precoder codebook is tailored for 2D antenna arrays by combining precoders tailored for a horizontal array and a vertical array respectively by means of a Kronecker product. This means that (at least part of) the precoder can be described as a function of

$$W_H \otimes W_V$$

where W_H is a horizontal precoder taken from a (sub)-codebook $\boldsymbol{X}_H$ containing N_H codewords and similarly W_V is a vertical precoder taken from a (sub)-codebook $\boldsymbol{X}_V$ containing N_V codewords. The joint codebook, denoted $\boldsymbol{X}_H \otimes \boldsymbol{X}_V$, thus contains $N_H \cdot N_V$ codewords. The elements of $\boldsymbol{X}_H$ are indexed with $k = 0, \ldots, N_H - 1$, the elements of $\boldsymbol{X}_V$ are indexed with $l = 0, \ldots, N_V - 1$ and the elements of the joint codebook $\boldsymbol{X}_H \otimes \boldsymbol{X}_V$ are indexed with $m = N_V \cdot k + l$ meaning that $m = 0, \ldots, N_H \cdot N_V - 1$.

[0029] In some embodiments, for example, the (sub)-codebooks of the Kronecker codebook consist of DFT-precoders. In this case, the horizontal codebook can be expressed as $\boldsymbol{X}_H^k = \left[1 \ e^{j2\pi\frac{1k+\Delta_h}{M_h Q_h}} \ \cdots \ e^{j2\pi\frac{(M_h-1)k+\Delta_h}{M_h Q_h}}\right]^T$, $k = 0, \ldots, M_h Q_h - 1$, where Q_h is an integer horizontal oversampling factor and Δ_h can take on value in the interval 0 to 1 so as to "shift" the beam pattern (Δ_h =0.5 could be an interesting value for creating symmetry of beams with respect to the broadside of an array). And the vertical codebook can be expressed as

$\boldsymbol{X}_V^l = \left[1 \ e^{j2\pi\frac{1l+\Delta_v}{M_v Q_v}} \ \cdots \ e^{j2\pi\frac{(M_v-1)l+\Delta_v}{M_v Q_v}}\right]^T$, $l = 0, \ldots, M_v Q_v - 1$, where $Q_v$is an integer vertical oversampling factor and Δ_v is similarly defined as above.

[0030] It should be pointed out that a precoder codebook may be defined in several ways. For example, the above mentioned Kronecker codebook may be interpreted as one codebook indexed with a single PMI m. Alternatively, it may be interpreted as a single codebook indexed with two PMIs k and l. It may also be interpreted as two separate codebooks, indexed with k and l respectivly. Further, the Kronecker codebook discussed above may only describe a part of the precoder, i.e. the precoder may be a function of other parameters as well. In a such example, the precoder is a function also of another PMI n. Again, this can be interpreted as three separate codebooks with indices k, l and n respectively, or two separate codebooks with indices $m = N_V \cdot k + l$ and n respectivly. It may also be interpreted as a single joint codebook with a joint PMI. Embodiments herein should be considered agnostic with respect to how a codebook is defined.

[0031] With this understanding, the codebook at issue in Figure 2 may be a Kronecker codebook that comprises different precoders indexed (at least in part) by different possible values of a single index parameter (e.g., index parameter $m = 0, \ldots, N_H \cdot N_V - 1$). In this case, the different possible values of the single index parameter are divided into different clusters of consecutively ordered values. And precoders in the different groups are respectively indexed (at least in part) by the different clusters of consecutively ordered values. For example, precoders indexed by the cluster $m = 0, \ldots m1$ belong to a first group, precoders indexed by the cluster $m = m2, \ldots m3$ belong to a second group, precoders indexed by the cluster $m = m4, \ldots m5$ belong to a third group, and so on. As an even more specific example, one or more embodiments exploit the Kronecker structure of the precoder by mapping the index m to indices k and l as $m = N_v k + l$ and grouping the precoders such that m = 0,...,Nv-1 is the first group, m= Nv,...,2Nv-1 is the second group , etc.

[0032] In another embodiment, by contrast, the Kronecker codebook comprises different precoders indexed (at least in part) by different pairs of possible values for a first-dimension index parameter (e.g., $k = 0, \ldots, N_H - 1$) and a second-dimension index parameter (e.g., $l = 0, \ldots, N_V - 1$). In this case, precoders in each of the different groups are indexed (at least in part) by pairs (k, l) that have the same value for the first-dimension index parameter k and/or the second-dimension index parameter l.

[0033] Two different embodiments in this regard, referred to as a "similar rows embodiment" and a "similar columns embodiment", will now be illustrated in the context of a Kronecker codebook and where only a single reference configuration is defined for a group. The Kronecker codebook in this example consists of precoders with different angular directions, spanning a two-dimensional angular area as seen from the transmitter. An important use case for codebook subset restriction in such an embodiment may be to restrict precoders in a certain angular area or angle interval, e.g. corresponding to a direction where a user hotspot of an adjacent cell is located. The eNodeB would then reduce interference to said adjacent cell and particular the hotspot area if precoders corresponding to beams pointing at that direction were restricted. This is beneficial from a system capacity perspective.

[0034] In the following, consider the specific example where codebook subset restriction is used on a Kronecker codebook in order to understand how different embodiments can be used to reduce the signaling overhead. In this scenario, a 4x4 antenna array with a mechanical downtilt of $18°$ is used. The Kronecker codebook consists of 8 vertical and 8 horizontal precoders, i.e. $N_H = N_V = 8$. The angular pointing directions of the precoders in the codebook are illustrated in Figure 4.

[0035] Codebook subset restriction is applied to restrict beams with pointing directions in the zenith interval $[85°, 95°]$ (illustrated with dotted lines). That is, codebook subset restriction is applied in the angular interval $85° < \theta < 95°$, meaning that the precoders with indices $(k, l) = (0,4), (3,5), (4,5), (7,4)$ are restricted. These restricted beams are illustrated with an 'o' while the unrestricted beams are illustrated with an 'x'. The beam index k in the horizontal codebook and l in the vertical codebook is written next to the beams as (k, l). If this configuration of codebook subset restriction would be signaled with a conventional bitmap, $N = N_H \cdot N_V = 64$ bits would be used.

"Similar rows embodiment"

[0036] In one embodiment, by using compressing of the CSR signalling, a scheme is designed taking into consideration the hypothesis that precoders (k, l) with adjacent l-indices (i.e. $(k, l_0 - 1), (k, l_0)$ and $(k, l_0 + 1)$) are likely to have the same restriction setting, meaning that if (k, l_0) is restricted, $(k, l_0 + 1)$ is likely to be restricted as well and vice versa. The scheme works as follows:

[0037] First, a bitmap of N_H bits are sent, indicating the codebook subset restriction for the "row" of precoders where $l = 0$ (c.f. Figure 4), i.e the precoders $(k,l) = (0,0),(1,0),\ldots,(N_H - 1,0)$.

[0038] Then, the codebook subset restriction for the second "row" of precoders, where $l = 1$ is sent. If the restriction is the same as for the previous row of precoders, a '1' is sent. If the restriction for this row differs from the restriction of the previous row, a '0' is sent, followed by a bitmap indicating the restriction for this row.

[0039] The previous step is then repeated for each of the N_V "rows" of precoders.

[0040] We illustrate this embodiment with an example, considering the codebook subset restriction setting illustrated in Figure 4, i.e. the restriction of precoders with indices $(k,l) = (0,4),(3,5),(4,5),(7,4)$ should be signaled.

[0041] For $l = 0$:

No precoders with l-index 0 should be restricted, therefore the bitmap '00000000' is sent.

[0042] For $l = 1$:

The restriction of this row is identical to the restriction of the previous row, the bit '1' is sent.

[0043] For $l = 2$:

The restriction of this row is identical to the restriction of the previous row, the bit '1' is sent.

[0044] For $l = 3$:

The restriction of this row is identical to the restriction of the previous row, the bit '1' is sent.

[0045] For $l = 4$:

The restriction of this row is not identical to the restriction of the previous row, therefore the bit '0' is sent. The bitmap indicating the restriction for this row should now be sent. Precoders (0,4) and (7,4) should be restricted. Therefore, the bitmap '10000001' is sent.

[0046] For $l = 5$:

The restriction of this row is not identical to the restriction of the previous row, therefore the bit '0' is sent. The bitmap indicating the restriction for this row should now be sent. Precoders (3,5) and (4,5) should be restricted. Therefore, the bitmap '00011000' is sent.

[0047] For $l = 6$:

The restriction of this row is not identical to the restriction of the previous row, therefore the bit '0' is sent. The bitmap indicating the restriction for this row should now be sent. No precoder should be restricted. Therefore, the bitmap '00000000' is sent.

[0048] For $l = 7$:

The restriction of this row is identical to the restriction of the previous row, the bit '1' is sent.

[0049] The string of bits to be signaled is thus 000000000111010000001000011000000000000001', consisting of 39 bits. Generally, the number of bits required with this scheme is

$$N_{bits} = M \cdot N_H + N_V - 1$$

[0050] Where M is the number of times the rows change and a bitmap for a row has to be transmitted, $M = 4$ in the example. Analyzing the above expression, we note that $1 \leq M \leq N_V$. This means that for some of the $2^N = 2^{N_H \cdot N_V}$ possible codebook subset restrictions, the number of bits required to signal the codebook subset restriction with this scheme is smaller than N, while for others, such as when $M = N_V$, the number of bits required is larger than N.

[0051] It should be noted that this is a small example for the sake of illustrating the embodiment. If a larger codebook is used, say $N_H = N_V = 30$, and $M = 4$ the number of bits required with this scheme would be $N_{bits} = M \cdot N_H + N_V - 1 = 149$ compared to $N = N_H \cdot N_V = 900$ in the case of just transmitting the entire bitmap; this is hence a substantial reduction in the number of required bits.

[0052] Finally, it is pointed out that all possible codebook subset restriction configurations can be represented by this encoding/decoding scheme, thereby providing full flexibility.

"Similar columns" embodiment

[0053] In another embodiment, the scheme discussed in the previous embodiment is modified by instead taking into consideration the hypothesis that precoders (k, l) with adjacent k-indices (i.e. $(k_0 - 1, l), (k_0, l)$ and $(k_0 + 1, l)$) are likely to have the same restriction setting, meaning that if (k_0, l) is restricted, $(k_0 + 1, l)$ is likely to be restricted as well and vice versa. The construction of the string of bits to be signaled would then work similarly as in the previously discussed embodiment, except that the precoders "columns" k will be used instead.

[0054] In another embodiment an extra initial bit is inserted where '1' indicates that encoding is done under the assumption that precoders (k, l) with adjacent l-indices (i.e. $(k, l_0 - 1), (k, l_0)$ and $(k, l_0 + 1)$) are likely to have the same restriction, hence the encoding is done row wise, whereas a '0' indicates that precoders (k, l) with adjacent k-indices (i.e. $(k_0 - 1, l), (k_0, l)$ and $(k_0 + 1, l)$) are likely to have the same restriction setting, hence encoding is done column wise.

[0055] In another embodiment an initial bit is inserted where '1' indicates that no precoders are restricted, a '0' indicates that some precoders are restricted and the '0' is followed by a number of bits representing the codebook subset restriction.

[0056] Accordingly, different "compression" techniques (whether based on similar rows, columns, or otherwise) may be adopted for different groups of precoders in the same codebook, where the particular technique is indicated to the device so that the device can decode the signaling. Alternatively, the same "compression" technique may be adopted for each of the groups of precoders, but the network evaluates different possible techniques to identify the one that provides the best compression and then adopts that approach (and indicates it to the device).

[0057] Of course, the embodiments shown in Figure 2, and variations thereof, may be used for signaling a restricted subset of precoders in any given codebook, whether Kronecker structured or not. Moreover, the signaling may be rank-specific, meaning that different signaling restricts different rank-specific codebooks.

[0058] According to other embodiments shown in Figure 5, a method is implemented in a network node (e.g., a base station) for signaling to a wireless communication device which precoders in a codebook are restricted from being used (e.g., which Kronecker product precoders are restricted). As shown, the method includes generating codebook subset restriction signaling that, for each of one or more groups of precoders, jointly restricts the precoders in the group, e.g., with a single signaling bit (Block 210). In at least some embodiments, this signaling (i) is rank-agnostic so as to restrict precoders irrespective of their transmission rank; and/or (ii) jointly restricts a group of precoders by restricting a certain component that those precoders have in common. Regardless, the method then includes sending the generated signaling to the wireless communication device (Block 220).

[0059] Consider embodiments that jointly restrict a group of precoders by restricting a certain component that those precoders have in common. Precoders have a certain component in common if the precoders are derived from or are otherwise a function of that same component. In one embodiment, for example, a group of precoders $W(b)$ that have a certain component b in common are jointly restricted by restricting that component b. Restriction of this component b may be signaled for instance in terms of one or more indices for the component (e.g., m where the component is indexed as b_m or (k,l) where the component is indexed as $b_{k,l}$, with m, k, and l being indices for a Kronecker-structured codebook as described above).

[0060] Note that embodiments herein contemplate a precoder having one or more different "components" at any level of granularity. For example, a precoder may comprise one or more different components b at one level of granularity. At a finer level of granularity, though, each of these components b may in turn be derived from or otherwise be a function of multiple sub-components x_H and x_V such that $b(x_{H,}x_V)$. In this case, a group of precoders $W(x_{H,}x_V)$ that have a certain component x_H or x_V in common may be jointly restricted by restricting that component x_H or x_V. Restriction of this component x_H or x_V may be signaled for instance in terms of an index for the component (e.g., k or l where the component x_H is indexed as x_H^k and the component x_V is indexed as x_V^l, with x_H and x_V being horizontal and vertical beamforming vectors, respectively, and with k and l being indices for a Kronecker-structured codebook as described above).

[0061] In some embodiments, a precoder at one level of granularity consists of one or more different components that are referred to as one or more so-called "beam precoders". Each precoder W in this regard consists of one or more beamforming vectors $b_0, b_1, \ldots, b_X$ that are referred to as beam precoders. One or more embodiments herein jointly restrict a group of precoders W that have a certain beam precoder in common, by restricting that beam precoder. With restriction of precoders W as a whole founded on restriction of one or more of their constituting beam precoders, these embodiments advantageously generate the CSR signaling in terms of beam-specific restrictions (i.e., restrictions of certain beam precoders), rather than in terms of precoder-specific restrictions (i.e., restrictions on precoders W as a whole). In some embodiments, the device shall assume that a precoder W is restricted if one or more of its beam precoders are restricted. In other embodiments, each beam precoder must be restricted for the device to assume that the total precoder W is restricted.

[0062] In one embodiment, a beam precoder is the beamforming vector used to transmit on a particular layer, where different scaled versions of that beamforming vector are transmitted on different polarizations. Different layers are transmitted on different beam precoders. A precoder W in this case can be expressed as:

$$W = \alpha \cdot \begin{bmatrix} b_0 & b_1 & \cdots & b_{L-1} \\ \varphi_0 b_0 & \varphi_1 b_1 & \cdots & \varphi_{L-1} b_{L-1} \end{bmatrix}$$

Here, W is a $N \times L$ precoder matrix, where N is the number of transmit antenna ports, L the transmission rank (i.e. the number of transmitted spatial streams), $b_0, b_1, \ldots, b_{L-1}$ are $\frac{N}{2} \times 1$ beamforming vectors (denoted beam precoders), $\varphi_0, \varphi_1, \ldots, \varphi_{L-1}$ and α are arbitrary complex numbers. In some embodiments, the first $\frac{N}{2}$ antenna ports are mapped to antennas with one polarization while the latter $\frac{N}{2}$ antenna ports are mapped to antennas with the same positions as the first antennas, but with an orthogonal polarization. In such embodiments, for each column of W (i.e. the precoder for each spatial layer), a beam precoder b is transmitted on one polarization and a scaled version of the same beam precoder φb is transmitted on a second polarization.

[0063] In another embodiment, a beam precoder is the beamforming vector used to transmit on multiple different layers, where the layers are sent on orthogonal polarizations. In this case, a precoder W can be expressed as:

$$W = \alpha \cdot \begin{bmatrix} b_0 & b_0 & \cdots & b_0 \\ \varphi_0 b_0 & \varphi_1 b_0 & \cdots & \varphi_{L-1} b_0 \end{bmatrix}$$

Accordingly, it should be noted that the beam precoders for each spatial layer $b_0, b_1, \ldots, b_{L-1}$ may be different beam precoders, or, some subsets of the beam precoders may be identical, for example b_0 may be equal to b_1.

[0064] In yet another embodiment, a beam precoder is the beamforming vector used to transmit on a particular layer and on a particular polarization. That is, a beam precoder may be defined in a slightly different way than the definition above. The definition of a beam precoder may for example allow different beam precoders to be transmitted on the different polarizations of the same layer, such as

$$W = \alpha \cdot \begin{bmatrix} b_0 & b_2 & \cdots & b_{2L-2} \\ \varphi_0 b_1 & \varphi_1 b_3 & \cdots & \varphi_{L-1} b_{2L-1} \end{bmatrix}.$$

[0065] In still another embodiment, the beam precoders may be defined by disregarding the polarization as

$$W = \alpha \cdot [b_0 \quad b_1 \quad \ldots \quad b_{L-1}].$$

[0066] Note that the beam precoders $b_0, b_1, \ldots, b_{L-1}$ may be chosen explicitly from a set of beam precoders (a codebook) or they may be implicitly chosen when selecting the (total) precoder W from a codebook $\boldsymbol{X}$. It should be noted that the selection of the (total) precoder W may be made with one or several PMIs. In the case where selection of the total precoder W is made with several PMIs, the resulting beam precoders for each layer may be a function of only a subset of the PMIs or they may be a function of all PMIs.

[0067] Irrespective of the particular way a beam precoder is defined, though, one or more embodiments herein jointly restrict a group of precoders W that have a certain beam precoder in common, by restricting that beam precoder. That is, in some embodiments, codebook subset restriction (CSR) may be signalled based on the set of possible beam precoders b, instead of CSR signalled on the set of possible (total) precoders W. In some such embodiments, the UE shall assume that a precoder W is restricted if one or more of the beam precoders $b_0, b_1, \ldots, b_{L-1}$ of each layer are restricted. In other such embodiments, each layers' beam precoder must be restricted for the UE to assume that the total precoder W is restricted.

[0068] Consider a specific example for an 8TX codebook with transmission rank 2. In some embodiments, this codebook is defined as shown in Figure 6. Defined in this way, each precoder W is formed in part from a beam precoder v_m. The beam precoder index m is the same for some precoders W, including for instance precoders whose subcodebook index i_2 is equal to 0, 1, 8, 9, 12 or 13 (since for those precoders $m = 2i_1$). This means that those precoders W have the same beam precoder v_m in common. Accordingly, some embodiments herein jointly restrict a group of precoders W that have a particular beam precoder v_m in common, by restricting that beam precoder v_m, e.g., with a single bit. Restriction of this beam precoder v_m may be signaled for instance in terms of index m (e.g., beam precoders indexed with a particular value of m are restricted). Signaling in this case may constitute a bitmap of m values, with different bits in the bitmap respectively dedicated to indicating whether or not beam precoders indexed with different of m values are restricted from use.

[0069] In alternative embodiments not shown in Figure 6, the beam precoder v_m is replaced by beam precoder $v_{k,l}$, which is a Kronecker product of a vertical beamforming vector x_V with index k and a horizontal beamforming vector x_H with index l. Restriction of beam precoder $v_{k,l}$ may be signaled in terms of the index pair (k, l). Signaling in this case may constitute a bitmap of (k, l) value pairs, with different bits in the bitmap respectively dedicated to indicating whether or not beam precoders indexed with different (k, l) value pairs are restricted from use.

[0070] Instead of such a bitmap, restriction of one or more beam precoders $v_{k,l}$ in some embodiments is jointly signaled in terms of a "rectangle" defined by two (k, l) value pairs: namely, (k_0, l_0) and (k_1, l_1). In this case, beam precoders $v_{k,l}$ with indides $k_0 < k < k_1$ and $l_0 < l < l_1$ are restricted.

[0071] As yet another alternative, restriction of one or more beam precoders $v_{k,l}$ in some embodiments is signaled in terms of a bitmap of k values and/or a bitmap of l values. If signaled as only a bitmap of k values, the device in some embodiments assumes that any beam precoders $v_{k,l}$ with certain k values are restricted, irrespective of those precoders' l values. If signaled as only a bitmap of l values, the device in some embodiments assumes that any beam precoders $v_{k,l}$ with certain l values are restricted, irrespective of those precoders' k values. If signaled as both a bitmap of k values and a bitmap of l values, the device in some embodiments assumes that only beam precoders $v_{k,l}$ with certain (k, l) value pairs as collectively defined by those bitmaps are restricted.

[0072] That said, restrictions specified in term of k and/or l values may in some sense be deemed as restrictions at a finer level of granularity than even the beam precoders themselves. Indeed, as noted above, each beam precoder $v_{k,l}$, is in some embodiments a Kronecker product of a vertical beamforming vector x_V with index k and a horizontal beamforming vector x_H with index l. Accordingly, signaling the restriction as k and/or l values effectively amounts to restricting (sub)components x_H or x_V.

[0073] Consider a simple example of these finer-granularity embodiments where codebook subset restriction is to be applied to beam precoders with l values of 3 or 4. If this configuration of codebook subset restriction would be signaled with a conventional bitmap, $N = N_H \cdot N_V = 64$ bits would be used. By contrast, the scheme in these finer-granularity embodiments consider restriction of entire precoder "rows", i.e all precoders that are formed from beam precoders with the same l-index is either turned on or off. To signal the codebook subset restriction in this example, therefore, the bitmap '00011000' of l values, consisting of $N_V = 8$ bits, may be sent. With this scheme, a large reduction of the number of bits required to signal the codebook subset restriction is seen. However, not all of the 2^N possible codebook subset restrictions may be signaled.

[0074] In a similar embodiment, the restriction is applied on the precoder "columns" k and the codebook subset restriction is signaled with a N_H bit long bitmap, indicating restrictions of entire precoder "columns".

[0075] In another embodiment an extra initial bit is inserted where '1' indicates that encoding is done as above "row wise", whereas a '0' indicates is done "column wise".

[0076] In yet another embodiment, the device shall assume that a precoder W is restricted if both the vertical and the horizontal precoder in the Kronecker structure are restricted. If only one of the vertical and horizontal precoders are restricted, then the UE shall not assume that the resulting precoder after Kronecker operation is restricted.

[0077] Thus, one or more embodiments herein advantageously exploit a codebook's Kronecker structure to generate the signaling of Figure 5 in terms of indices k, l, and/or m. In some embodiments, for example, the signaling is generated to jointly restrict, e.g., with a single bit, a group of precoders that either (i) have the same value of index k; (ii) have the same value of index l; or (iii) have the same pair of values for indices (k, l).

[0078] In some embodiments, signaling that jointly restricts a group of precoders by restricting a certain component (e.g., beam precoder) that those precoders have in common is rank-agnostic. That is, the signaling jointly restricts the group of precoders regardless of the precoders' transmission rank (i.e., regardless of which rank-specific codebook they belong to). For example, embodiments that restrict a single beam precoder b_0 can be extended so that all precoders across all ranks that contain the restricted beam precoder b_0 are restricted. Hence, all precoders across all ranks that contain a certain beam precoder b_0 is a precoder group that can be restricted jointly. According to some embodiments, therefore, an advantage of signaling CSR based on beam precoders is that one does not need to signal a separate CSR for precoders with different rank (precoders with different rank are restricted with the same CSR). This reduces signaling overhead.

[0079] Signaling that jointly restricts a group of precoders by restricting a certain component that those precoders have in common also proves effective for restricting precoders that transmit in whole or in part towards certain angular pointing directions. Indeed, according to some embodiments herein, the network node jointly restricts a group of precoders that transmit at least in part towards a certain angular pointing direction, by restricting a certain component (e.g., beam precoder) which has that angular pointing direction. In this way, the network node avoids transmitting energy in a certain direction, by signaling to the device by means of CSR that the device shall not compute feedback for that particular direction.

[0080] More specifically in this regard, when each precoder W is formed from multiple beam precoders, the precoder W in some sense has multiple angular pointing directions corresponding to the angular pointing directions of its constituent beam precoders (where each beam precoder has its own azimuth and zenith angular pointing direction for example). In another sense, though, the precoder W has an overall angular pointing direction that is a combination (e.g., average) of its beam precoders' respective directions. By restricting beam precoders that have certain angular pointing directions, embodiments herein effectively restrict precoders that transmit at least in part in those directions, and do so with reduced signaling overhead.

[0081] As a simple example, a set of rank-1 precoders with the same angular pointing direction but with different polarization properties, such as the whole set of rank-1 precoders

$$\begin{bmatrix} b_0 \\ e^{j\omega_0} b_0 \end{bmatrix}, \begin{bmatrix} b_0 \\ e^{j\omega_1} b_0 \end{bmatrix}, \begin{bmatrix} b_0 \\ e^{j\omega_2} b_0 \end{bmatrix},$$

may be restricted by restriction signaling of a single beam precoder b_0. That is, when a restriction is signaled for a certain beam precoder, the restriction applies implicitly to all polarization phases of the signaled beam. Hence, the group of rank-1 precoders exemplified above is associated with a single CSR bit and is thus jointly restricted. This reduces device complexity and CSR signaling overhead, since on the beam direction needs to be signaled.

[0082] In another example, the set of rank-1 precoders

$$\begin{bmatrix} b_0 \\ e^{j\omega_0} b_1 \end{bmatrix}, \begin{bmatrix} b_2 \\ e^{j\omega_1} b_0 \end{bmatrix}, \begin{bmatrix} b_0 \\ e^{j\omega_2} b_2 \end{bmatrix},$$

may be jointly restricted by restriction signaling of a single beam precoder b_0. Hence, the group of rank-1 precoders exemplified above is associated with a single CSR bit and is thus jointly restricted.

[0083] Restriction of precoders with certain angular pointing directions can also be accomplished by specifying restrictions in terms of certain k and/or l values. This is illustrated with reference to Figure 7, which illustrates the angular beam pointing directions of rank-1 precoders in a codebook according to one example. In this example, the network node has a 4x4 antenna array where no mechanical downtilt is used. The Kronecker codebook consists of 8 vertical and 8 horizontal precoders, i.e. $N_H = N_V = 8$. In this example, codebook subset restriction is applied to restrict beams with pointing directions in the zenith interval $[80°, 100°]$ (the interval is illustrated with dotted lines). That is, codebook subset restriction is applied in the angular interval $80° < \theta < 100°$, such that the precoders with indices l-index 3 and 4 are restricted. The restricted beams are illustrated with an 'o' while the unrestricted beams are illustrated with an 'x'. The beam index k in the horizontal codebook and l in the vertical codebook is written next to the beams as (k, l). To signal the codebook subset restriction in this example, therefore, the bitmap '00011000' of l values, consisting of $N_V = 8$ bits, may be sent. With this scheme, a large reduction of the number of bits required to signal the codebook subset restriction is seen.

[0084] In another embodiment, the device shall assume that a precoder is restricted if both the vertical and horizontal precoder in the Kronecker structure are restricted. This allows to restrict a rectangular "window" of beam former pointing angles as seen from the network node.

[0085] This can also be accomplished by signaling the restriction as a "rectangle" of precoders defined by the index pairs (k_0, l_0) and (k_1, l_1). With this scheme, precoders with indides $k_0 < k < k_1$and $l_0 < l < l_1$ are restricted.

[0086] Component-based restriction of a precoder group is just one example of embodiments that provide for rank-agnostic CSR signalling. Other embodiments herein also provide for such rank-agnostic signaling. For example, some embodiments herein generate signaling to jointly indicate that a group of precoders which transmit in whole or in part in certain angular pointing direction(s) are restricted, by generating the signaling to (explicitly or implicitly) indicate those angular pointing direction(s). The signaling may for instance specify an angular area or interval that is restricted, in terms of one or more angular parameters. This restriction may concern the angular pointing direction of a precoder as a whole, or the angular pointing direction of any beam precoder forming the precoder.

[0087] In one embodiment, the angular area or interval may be represented by angular points (ϕ_0,θ_0) and (ϕ_1,θ_1), spanning a rectangle in the angular domain. Here, ϕ and θ are the azimuth and zenith angles with respect to the eNodeB respectivly. Multiple such rectangular areas may be signaled although the present embodiment focuses on the case of a single rectangular area for simplicity. The UE may then calculate the angular pointing directions of the precoders in the codebook and compare them to the restricted angular area to derive the codebook subset restriction. The UE may need some additional information regarding what to assume about the transmitter antenna array (which does not need to correspond to the actually used antenna array) to be able to calculate the pointing directions of the precoders. Consider an exemplary embodiment where the (sub)-codebooks of the Kronecker codebook consist of DFT-precoders, i.e

[0088] The horizontal codebook can be expressed as

$\boldsymbol{X}_H^k = \left[1 \; e^{j2\pi\frac{1k+\Delta_h}{M_hQ_h}} \; \cdots \; e^{j2\pi\frac{(M_h-1)k+\Delta_h}{M_hQ_h}}\right]^T$, $k = 0, \ldots, M_hQ_h - 1$, where Q_h is an integer horizontal oversampling factor and Δ_h can take on value in the interval 0 to 1 so as to "shift" the beam pattern (Δ_h =0.5 could be an interesting value for creating symmetry of beams with respect to the broadside of an array).

[0089] The vertical codebook can be expressed

as $\boldsymbol{X}_V^l = \left[1 \; e^{j2\pi\frac{1l+\Delta_v}{M_vQ_v}} \; \cdots \; e^{j2\pi\frac{(M_v-1)l+\Delta_v}{M_vQ_v}}\right]^T$, $l = 0, \ldots, M_vQ_v - 1$, where $Q_v$is an integer vertical oversampling factor and Δ_v is similarly defined as above.

[0090] The pointing direction of precoder (k,l) can be calculated by first calculating the pointing angle with respect to the broadside of the antenna array:

$$\tilde{\theta} = acos(\frac{k + \Delta - \frac{Q_v M_v}{2}}{d_V Q_v M_v})$$

$$\tilde{\phi} = asin(\frac{l + \Delta - \frac{Q_h M_h}{2}}{d_H Q_h M_h \, sin(\tilde{\theta})})$$

[0091] Where d_V and d_H is the vertical and horizontal antenna element spacing of the array, in wavelengths, respectively. The mechanical downtilt angle β is taken into account in order to calculate the actual beam pointing angles as:

$$\phi = \angle(cos(\tilde{\phi})\, sin(\tilde{\theta})\, cos(-\beta) - cos(\tilde{\theta})\, sin(-\beta) + j\, sin(\tilde{\theta})\, sin(\tilde{\theta}))$$

$$\theta = acos\big(cos(\tilde{\phi})\, sin(\tilde{\theta})\, sin(-\beta) + cos(-\beta)\, cos(\tilde{\theta})\big)$$

[0092] The UE needs to be signaled the additional information d_H, d_V and β to be able to calculate the beam pointing direction of the precoders in the codebook. It is assumed that the UE already knows the parameters Q_v, M_v, Q_h, M_h and Δ as part of the codebook structure.

[0093] The set of parameters $\phi_0, \theta_0, \phi_1, \theta_1, d_H, d_V, \beta$ thus parameterizes the codebook subset restriction in this embodiment. When signaling said parameters, several strategies may be used.

[0094] In one embodiment, each parameter is uniformly quantized with a number of bits, over a predefined interval. An example is given in the table below.

Parameters	Interval	Quantization bits
$\phi_0, \theta_0, \phi_1, \theta_1$	[0,180] [deg]	6
d_H, d_V	[0,2]	4
β	[-30,30] [deg]	6

[0095] In this embodiment, the number of bits required to signal the codebook subset restriction is 38. Note that this is independent of the codebook size.

[0096] In another embodiment, each parameter may take a value from a fixed set of possible values. Each possible value of the parameter is encoded with a different number of bits depending on e.g. the perceived likelihood of the parameter taking that value. For example, the horizontal array element spacing d_H may be encoded as follows

Value	0.5	0.8	0.65	1	4	2	0.75
Bits	1	01	0011	0010	0001	00001	00000

[0097] In this embodiment, the encoding of d_H was designed to take into account $d_H = 0.5$ is a common value for horizontal antenna element separation, thus encoding this value with a low number of bits. Other, less common, values are encoded with a larger number of bits. Note that the encoding of d_H in this embodiment constitutes a uniquely decodable code.

[0098] In another embodiment, some of the parameters are uniformly quantized with a number of bits over a predefined interval, while other parameters are encoded with a different number of bits as in the previous embodiment.

[0099] In some other embodiments, different sets of parameters relating to the restricted angular area may constitute the parameters that define the codebook subset restriction. In one such embodiment, only a zenith interval $\theta_0 \leq \theta < \theta_1$ is restricted, and thus, θ_0, θ_1 may be sent. In another such embodiment, the restriction is only an azimuth interval $\phi_0 \leq \phi < \phi_1$. In yet another such embodiment, the angle interval may be open-ended, i.e. $\phi < \phi_1$ constitutes the restriction.

[00100] In other embodiments, parameters relating to the antenna array such as d_H, d_V and Ψ are not a part of the codebook subset restriction parameters, instead they may be already known to the UE or the UE assumes a default value of said parameters and the eNodeB chooses restriction angles (ϕ_0, θ_0) and (ϕ_1, θ_1) in such a way that the intended precoders are restricted when the UE calculates the restriction based on the default values of said parameters, where the default values of said parameters may differ from the actual value of said parameters.

[00101] In other embodiments, more parameters may be included in the codebook subset restriction parameters. In one such embodiment, the roll angle γ of the antenna array may be included in the codebook subset restriction parameters.

[00102] In view of the above modifications and variations, one recognizes that there are many ways that the CSR signaling can jointly restrict precoders in a group. The signaling can be rank-agnostic or not. And the signaling can restrict a certain component that is common to the group or signal angular parameters associated with the group. The signaling can take the form of a bitmap for beam precoder indices, take the form of angular parameters, take the form of sub-codebook index pairs, take the form of a bitmap for indices of a single sub-codebook, etc. Irrespective of these particular variations, though, CSR signaling overhead is reduced based on correlation of the precoder restrictions or equivalently grouping of precoders. But the group-based joint restriction means that not all of the 2^N codebook subset restriction configurations are possible to convey to the device. Instead, only a subset of the possible configurations may be chosen.

[00103] Accordingly, at least some embodiments balance the loss in flexibility caused by joint restriction with the signaling overhead gains by such joint restriction by performing joint restriction with respect to only a portion of precoders in the codebook. That is, codebook subset restriction may be configured with full flexibility on a subset A of the precoders in the codebook (meaning that each of the precoders may be turned on or off individually), while only a few configurations may be chosen for the remaining set B of precoders. For example, the codebook subset restriction for the remaining set B of precoders may only be represented with one bit, turning all precoders in the set either on or off. This will reduce the CSR signaling overhead which is beneficial.

[00104] As an example in the context of beam precoders, the codebook may consist of two sets of precoders. One of the sets consist of precoders which may be equivalently expressed as a function of layer-specific beam precoders (as defined above) while the other set may consist of arbitrary precoders. In this embodiment, the first set of precoders may be configured with full flexibility while the other precoders in the codebook may be configured with limited flexibility.

[00105] This embodiment is just one example of grouping of the precoders in the codebook where precoders belonging to set A is individually represented by one bit while precoders in set B are all jointly restricted with a single bit. This embodiment can be further extended by having multiple sets B as B_1,B_2,... B_N where each of the set B_n, n=1,...,N contain at least two precoders each and is associated with one CSR bit. In Figure 8 an example is shown where Precoder 1 to 14 are each represented by an individual bit (Set A), while all precoders in group B1 are represented by a single CSR bit, e.g. the bit for precoder 15.

[00106] The defined groups may also be overlapping, so that a given precoder exists in multiple groups. If this is the case, then priority or combining rules needs to be defined, so that the UE understands how to interpret the case when one precoder is restricted by the signaling of one group but not from another group it belong to.

[00107] In a further detailed embodiment, therefore, the groups B_n in Figure 8 may be overlapping and rules are specified in standard text on how the UE shall interpret CSR signaling. For instance, assume two groups B_1 and B_2 each represented by one bit and that one precoder belongs to both groups. One rule may be that if a precoder is restricted in any of the groups it belongs, then the precoder should be assumed to be restricted. Another alternative is that the precoder must be restricted in both groups for the precoder to be assumed to be restricted.

[00108] In some embodiments in this disclosure, we discuss codebook subset restriction using the terminology *precoders* and *codebooks*. It may be assumed that beam specific restriction is used in said embodiments, and that the terminology may be interchanged to *beam precoders* and *set of beam precoders*.

[00109] Note that although terminology from 3GPP LTE has been used in this disclosure to exemplify embodiments herein, this should not be seen as limiting the scope of the embodiments to only the aforementioned system. Other wireless systems, including WCDMA, WiMax, UMB and GSM, may also benefit from exploiting the ideas covered within this disclosure.

[00110] Also note that terminology such as eNodeB and UE should be considering non-limiting and does in particular not imply a certain hierarchical relation between the two; in general "eNodeB" could be considered as device 1 and "UE" device 2, and these two devices communicate with each other over some radio channel. Herein, we also focus on wireless transmissions in the downlink, but embodiments herein are equally applicable in the uplink.

Corresponding Methods in a Wireless Communication Device

[00111] Embodiments herein also include methods in a wireless communication device corresponding to the methods described above in a network node. These methods receive and decode the signaling that the network node generates according to any of the embodiments above.

[00112] According to one embodiment shown in Figure 9, for example, a method is implemented by a wireless communication device (e.g., a UE) for decoding signaling from a network node indicating which precoders in a codebook are restricted from being used. The method includes receiving the signaling (Block 300). The method also includes, for each of one or more groups of precoders in the codebook, decoding the signaling to identify which of different possible configurations is actually signaled for that group. Different possible configurations in this regard restrict different subgroups of precoders in the group from being used. This decoding proceeds on a group-by-group basis, starting with a first group (Block 310). Specifically, the decoding entails identifying one or more reference configurations for the first group, the bit pattern identified for signaling each reference configuration, and the length of that bit pattern (Block 320). These reference configuration(s) may be predefined at the device, or may be signaled from the network node. Regardless, decoding then entails detecting the actual configuration signaled for the group, by detecting a bit pattern in the received signaling whose length depends on (i) whether the actual configuration matches one of the one or more reference configurations; and/or (ii) which reference configuration the actual configuration matches (Block 330).

[00113] Such may entail, for example, determining the length *B* of the bit pattern defined for signaling a particular reference configuration, and checking whether a *B*-length string of the next bits in the signaling corresponds to the bit pattern defined for signaling that reference configuration. This determination and checking may be performed for each of the one or more reference configurations, after which (if no reference configurations are identified as being signaled) a default-length string of the next bits in the signaling is decoded for detecting non-reference configurations.

[00114] Regardless of the particular implementation of the decoding process (Blocks 320-330), the decoding is repeated for each of the one or more groups of precoders in the codebook (Blocks 340, 350).

[00115] Those skilled in the art will appreciate that the device-side embodiments include decoding of any of the network-side embodiments illustrated with reference to Figure 3, including for instance the "similar rows embodiments" and the "similar columns embodiment."

[00116] According to one or more other embodiments shown in Figure 10, a method is implemented by a wireless communication device (e.g., a UE) for decoding signaling from a network node indicating which precoders in a codebook are restricted from being used (e.g., which Kronecker product precoders are restricted). As shown, the method includes receiving the signaling from a network node (e.g., a base station) (Block 400). The method also includes decoding the signaling as jointly restricting precoders in each of one or more groups of precoders (Block 410). In at least some embodiments, such decoding involves decoding the signaling (i) as being rank-agnostic so as to restrict precoders irrespective of their transmission rank; and/or (ii) as jointly restricting a group of precoders by restricting a certain component that those precoders have in common.

[00117] Those skilled in the art will appreciate that the device-side embodiments include decoding of any of the network-side embodiments illustrated with reference to Figure 5. So, for example, the device in some embodiments decodes the signaling as jointly restricting a group of precoders that have a certain beam precoder in common, by restricting that beam precoder. And one or more device-side embodiments likewise advantageously exploit a codebook's Kronecker structure to decode the signaling of Figure 10 in terms of indices k, l, and/or m. In some embodiments, for example, the signaling is decoding as jointly restricting, e.g., with a single bit, a group of precoders that either (i) have the same value of index k; (ii) have the same value of index l; or (iii) have the same pair of values for indices (k, l).

Network Node and Wireless Communication Device

[00118] With the above modifications and variations in mind, Figure 11 illustrates additional details of the network node 500 according to one or more embodiments. The network node 500 is configured, e.g., via functional means or units 540-570, to implement the processing in Figure 2 for signaling to a wireless communication device which precoders in a codebook are restricted from being used. The network node 500 in some embodiments for example includes a reference configuration identifying means or unit 540 for identifying one or more reference configurations for each of one or more groups of precoders. The network node 500 in such case further includes an actual configuration identifying means or unit 550 for identifying an actual configuration for each of the one or more groups. The network node 500 also includes a signal generating means or unit 560 for generating signaling to indicate the actual configuration for each of the one or more groups, by generating the signaling as a bit pattern whose length depends on (i) whether the actual configuration matches one of the one or more reference configurations; and/or (ii) which reference configuration the actual configuration matches. The network node 500 finally includes a sending means or unit 570 for sending the generated signaling to the wireless communication device.

[00119] In at least some embodiments, the network node 500 comprises one or more processing circuits 510 configured to implement this processing, such as by implementing functional means or units 540-570. In one embodiment, for example, the node's processing circuit(s) 510 implement functional means or units 540-570 as respective circuits. The circuits in this regard may comprise circuits dedicated to performing certain functional processing and/or one or more microprocessors in conjunction with memory 520. In embodiments that employ memory 520, which may comprise one or several types of memory such as read-only memory (ROM), random-access memory, cache memory, flash memory devices, optical storage devices, etc., the memory stores program code that, when executed by the one or more for carrying out one or more microprocessors, carries out the techniques described herein.

[00120] In one or more embodiments, the network node 500 also comprises one or more communication interfaces 530. The one or more communication interfaces 530 include various components (not shown) for sending and receiving data and control signals. More particularly, the interface(s) 530 include a transmitter that is configured to use known signal processing techniques, typically according to one or more standards, and is configured to condition a signal for transmission (e.g., over the air via one or more antennas). Similarly, the interface(s) 530 include a receiver that is configured to convert signals received (e.g., via the antenna(s)) into digital samples for processing by the one or more processing circuits 510.

[00121] Figure 12 illustrates additional details of the network node 600 according to one or more embodiments. The network node 600 is configured, e.g., via functional means or units 640-650, to implement the processing in Figure 5 for signaling to a wireless communication device which precoders in a codebook are restricted from being used. The network node 600 in some embodiments for example includes a generating means or unit 640 for generating codebook subset restriction signaling that, for each of one or more groups of precoders, jointly restricts the precoders in the group, e.g., with a single signaling bit. The network node 600 also includes a sending means or unit 650 for sending the generated signaling to the wireless communication device.

[00122] In at least some embodiments, the network node 600 comprises one or more processing circuits 610 configured to implement this processing, such as by implementing functional means or units 640-650. In one embodiment, for example, the node's processing circuit(s) 610 implement functional means or units 640-650 as respective circuits (similarly to that described above, e.g., in conjunction with memory 620). In one or more embodiments, the network node 600 also comprises one or more communication interfaces 630.

[00123] Figure 13 illustrates additional details of the wireless communication device 700 according to one or more embodiments. The device 700 is configured, e.g., via functional means or units 740-760, to implement the processing in Figure 9 for decoding signaling from a network node indicating which precoders in a codebook are restricted from being used. The device 700 in some embodiments for example includes a receiving means or unit 740 for receiving the signaling from the network node. The device 700 further includes an identifying means or unit 750 configured, for each of one or more groups of precoders, to identify one or more reference configurations for the group, the bit pattern identified for signaling each reference configuration, and the length of that bit pattern. The device 700 finally includes a detecting means or unit 760 configured to detect the actual configuration signaled for the group, by detecting a bit pattern in the received signaling whose length depends on (i) whether the actual configuration matches one of the one or more reference configurations; and/or (ii) which reference configuration the actual configuration matches.

[00124] In at least some embodiments, the device 700 comprises one or more processing circuits 710 configured to implement this processing, such as by implementing functional means or units 740-760. In one embodiment, for example, the device's processing circuit(s) 710 implement functional means or units 740-760 as respective circuits. The circuits in this regard may comprise circuits dedicated to performing certain functional processing and/or one or more microprocessors in conjunction with memory 720. In embodiments that employ memory 720, which may comprise one or several types of memory such as read-only memory (ROM), random-access memory, cache memory, flash memory devices, optical storage devices, etc., the memory stores program code that, when executed by the one or more for carrying out one or more microprocessors, carries out the techniques described herein.

[00125] In one or more embodiments, the device 700 also comprises one or more communication interfaces 730. The one or more communication interfaces 730 include various components (not shown) for sending and receiving data and control signals. More particularly, the interface(s) 730 include a transmitter that is configured to use known signal processing techniques, typically according to one or more standards, and is configured to condition a signal for transmission (e.g., over the air via one or more antennas). Similarly, the interface(s) 730 include a receiver that is configured to convert signals received (e.g., via the antenna(s)) into digital samples for processing by the one or more processing circuits 710.

[00126] Figure 14 illustrates additional details of the device 800 according to one or more other embodiments. The device 800 is configured, e.g., via functional means or units 840-850, to implement the processing in Figure 10 for decoding signaling from a network node indicating which precoders in a codebook are restricted from being used. The device 800 in some embodiments for example includes a receiving means or unit 840 for receiving the signaling from the network node. The device 800 further includes a decoding means or unit 850 for decoding the signaling as jointly restricting precoders in each of one or more groups of precoders.

[00127] In at least some embodiments, the device 800 comprises one or more processing circuits 810 configured to implement this processing, such as by implementing functional means or units 840-850. In one embodiment, for example, the device's processing circuit(s) 810 implement functional means or units 840-850 as respective circuits (similarly to that described above, e.g., in conjunction with memory 820). In one or more embodiments, the device 800 also comprises one or more communication interfaces 830.

Computer Program Embodiments

[00128] Those skilled in the art will also appreciate that embodiments herein further include corresponding computer programs.

[00129] A computer program comprises instructions which, when executed on at least one processor of the network node or the wireless communication device, cause node or device to carry out any of the respective processing described above. Embodiments further include a carrier containing such a computer program. This carrier may comprise one of an electronic signal, optical signal, radio signal, or computer readable storage medium.

[00130] A computer program in this regard may comprise one or more code modules corresponding to the means or units described above.

General Embodiments

[00131] In a first embodiment, a UE is able to receive messages in order to turn individual codewords on/off. The following holds for the set of possible messages:

- At least one of these messages, which correspond to a certain configuration out of the 2^N possible configurations, is represented by less than N bits.
- The message will contain information to define on/off for each individual codeword in the entire codebook.
- Each message is uniquely decodable to the UE and will correspond to one of the 2^N possible configurations.

[00132] In a second embodiment, the UE of the first embodiment is configured such that codebook subset restriction is done on beam precoders.

[00133] In a third embodiment, the UE of the first embodiment is configured such that codebook subset restriction is configured with full flexibility for a subset of precoders in the codebook, while codebook subset restriction is configured with a limited flexibility for other precoders in the codebook.

[00134] In a fourth embodiment, the UE of the third embodiment is configured such that the set of precoders for which codebook subset restriction is configured with full flexibility is the set of precoders that may be equivalently expressed as a function of layer-specific beam precoders.

[00135] In a fifth embodiment, the UE of the first embodiment is configured such that N = N_H· N_V from the Kronecker structure.

[00136] In a sixth embodiment, the UE of any of the first through the fifth embodiments is configured such that the information used to design the set of messages consists of information about angular intervals which are likely to be restricted.

[00137] In a seventh embodiment, the UE of the first embodiment is configured such that only a subset of the 2^N possible configurations may be configured.

[00138] In an eighth embodiment, the UE of the first embodiment is configured such that at least one of the messages, which corresponds to a certain configuration out of the 2^N possible configurations, is represented more than N bits.

[00139] In a ninth embodiment, the UE of the first embodiment is configured such that the set of messages are designed using information about the likelihood of certain configurations being chosen.

[00140] In a tenth embodiment, the UE of the first embodiment is configured such that the information about the likelihood of certain configurations being chosen is only an implicit assumption of the likelihoods.

[00141] In an eleventh embodiment, the UE of the first embodiment is configured such that a set of angles specifies the configuration.

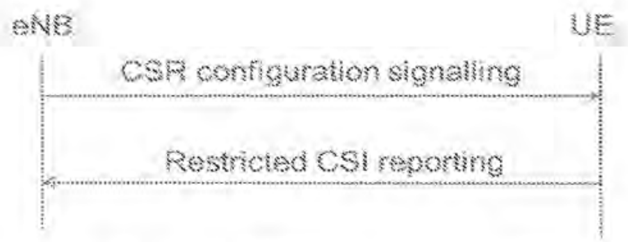

Figure 1 Configuration of CSR and associated CSI reporting

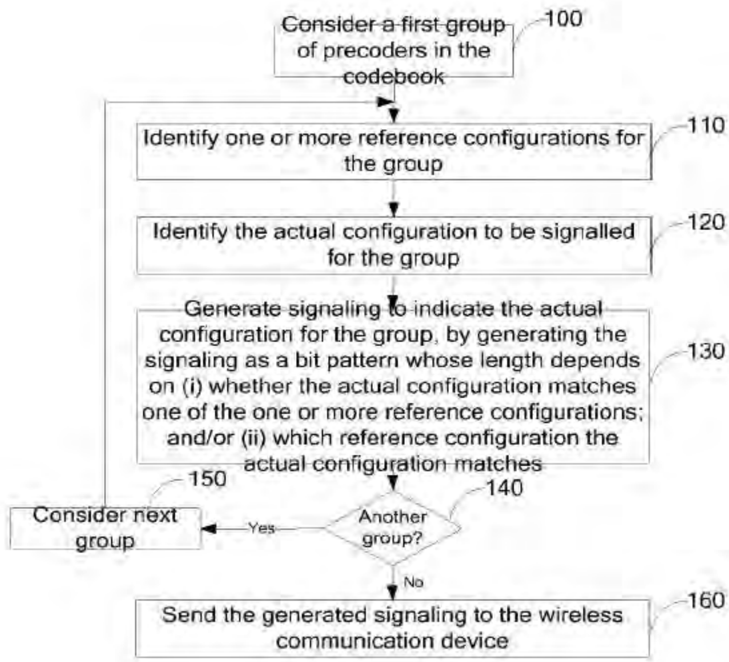

Figure 2

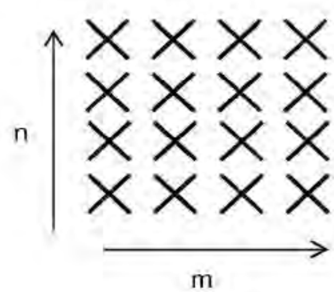

Figure 3

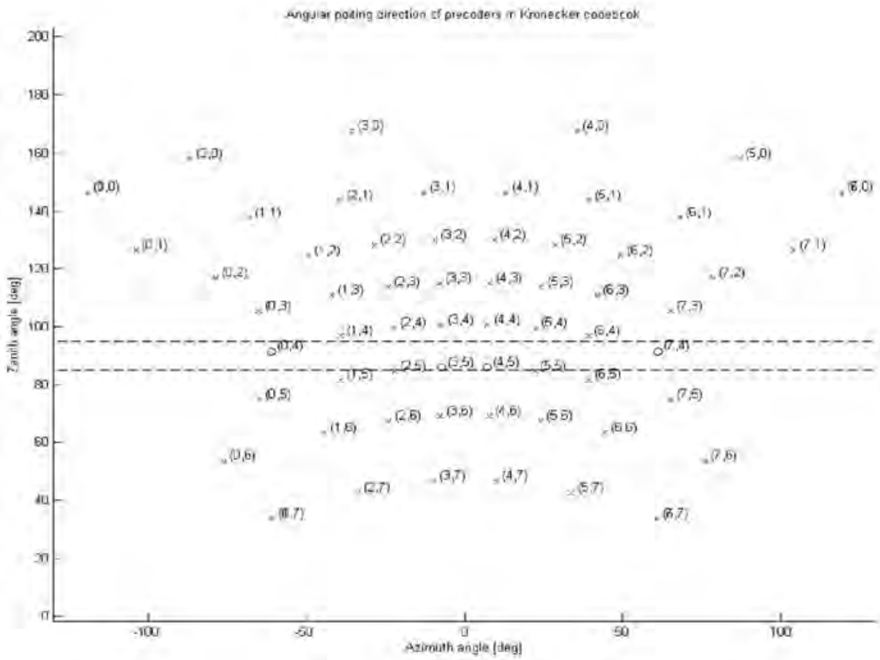

FIGURE 4
Angular Pointing Directions of Beams from a Kronecker Codebook with Mechanical Downtilt

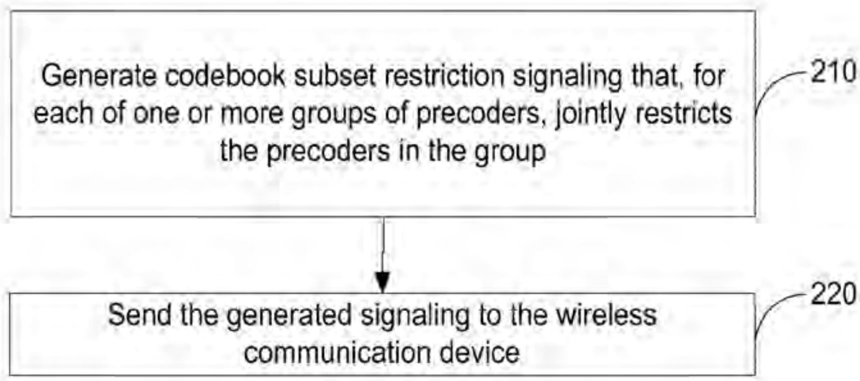
Generate codebook subset restriction signaling that, for each of one or more groups of precoders, jointly restricts the precoders in the group
210
Send the generated signaling to the wireless communication device
220

Figure 5

$$\varphi_n = e^{j\pi n/2}$$
$$v_m = \begin{bmatrix} 1 & e^{j2\pi m/32} & e^{j4\pi m/32} & e^{j6\pi m/32} \end{bmatrix}^T$$

Codebook for 2-layer CSI reporting using antenna ports 15 to 22

i_1	i_2			
	0	**1**	**2**	**3**
0 – 15	$W^{(2)}_{2i_1,2i_1,0}$	$W^{(2)}_{2i_1,2i_1,1}$	$W^{(2)}_{2i_1+1,2i_1+1,0}$	$W^{(2)}_{2i_1+1,2i_1+1,1}$
i_1	i_2			
	4	**5**	**6**	**7**
0 – 15	$W^{(2)}_{2i_1+2,2i_1+2,0}$	$W^{(2)}_{2i_1+2,2i_1+2,1}$	$W^{(2)}_{2i_1+3,2i_1+3,0}$	$W^{(2)}_{2i_1+3,2i_1+3,1}$
i_1	i_2			
	8	**9**	**10**	**11**
0 – 15	$W^{(2)}_{2i_1,2i_1+1,0}$	$W^{(2)}_{2i_1,2i_1+1,1}$	$W^{(2)}_{2i_1+1,2i_1+2,0}$	$W^{(2)}_{2i_1+1,2i_1+2,1}$
i_1	i_2			
	12	**13**	**14**	**15**
0 – 15	$W^{(2)}_{2i_1,2i_1+3,0}$	$W^{(2)}_{2i_1,2i_1+3,1}$	$W^{(2)}_{2i_1+1,2i_1+3,0}$	$W^{(2)}_{2i_1+1,2i_1+3,1}$
where $W^{(2)}_{m,m',n} = \frac{1}{4}\begin{bmatrix} v_m & v_{m'} \\ \varphi_n v_m & -\varphi_n v_{m'} \end{bmatrix}$				

Figure 6

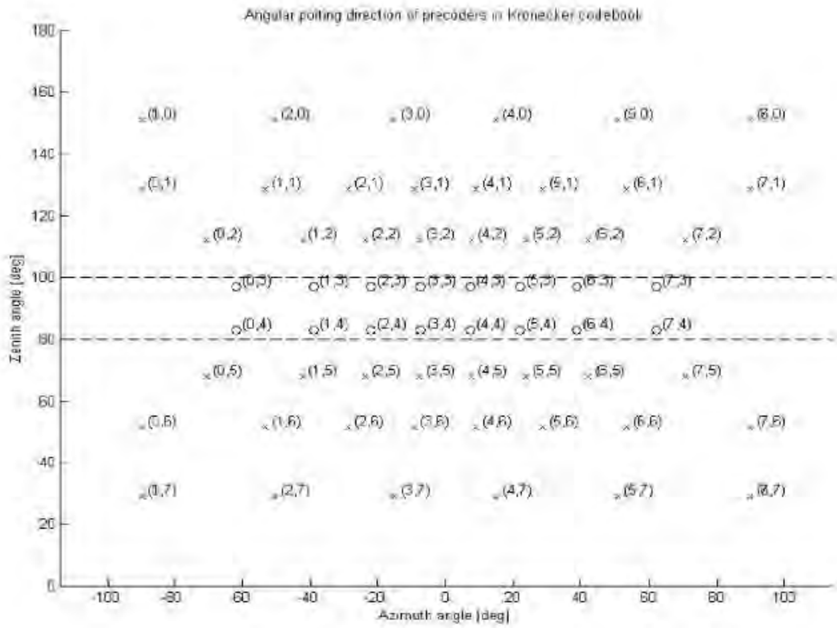

FIGURE 7
Angular Pointing Directions of Beams from a Kronecker Codebook with no Mechanical Downtilt

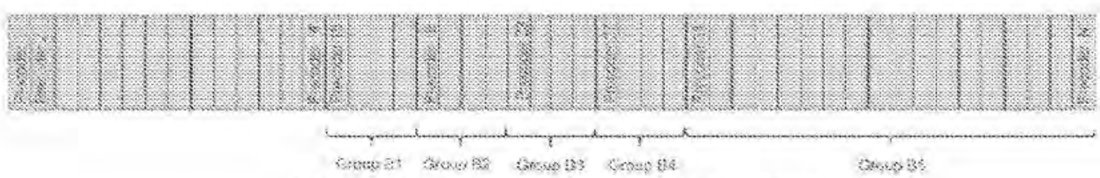

Figure 8 Example of grouping of precoders

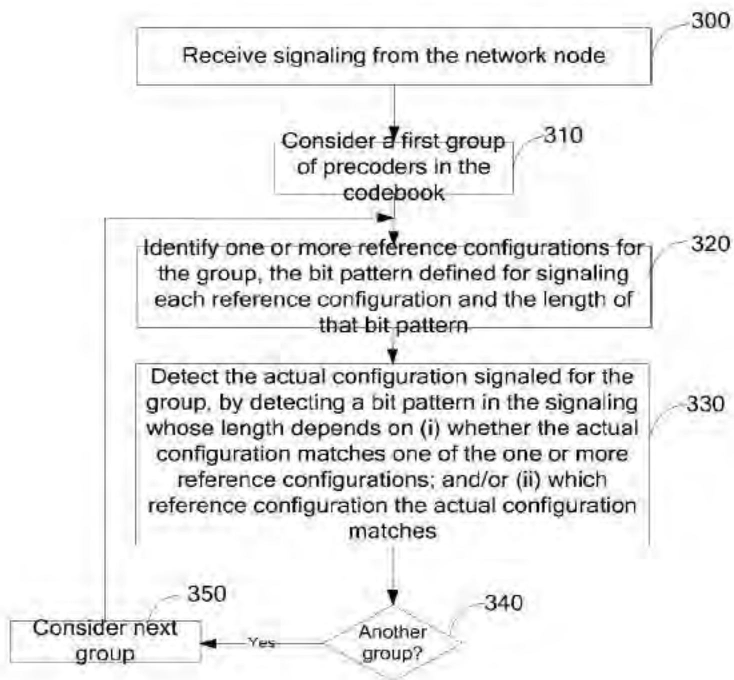

Figure 9

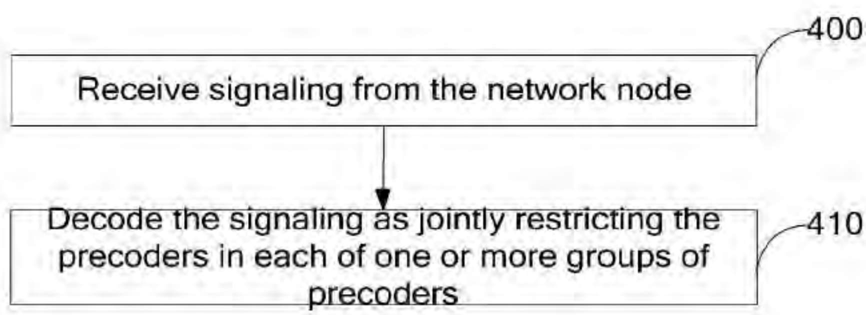

Figure 10

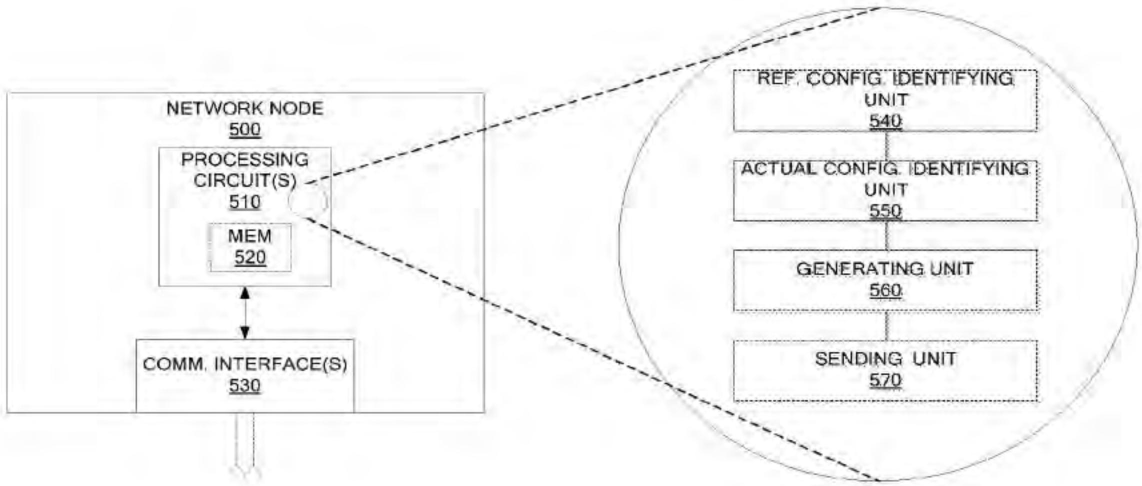

FIGURE 11

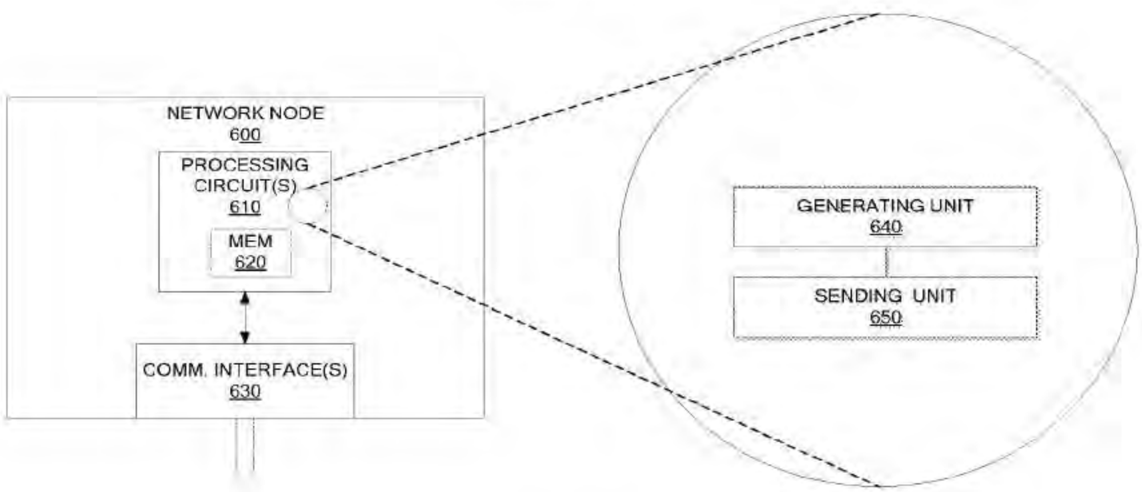

FIGURE 12

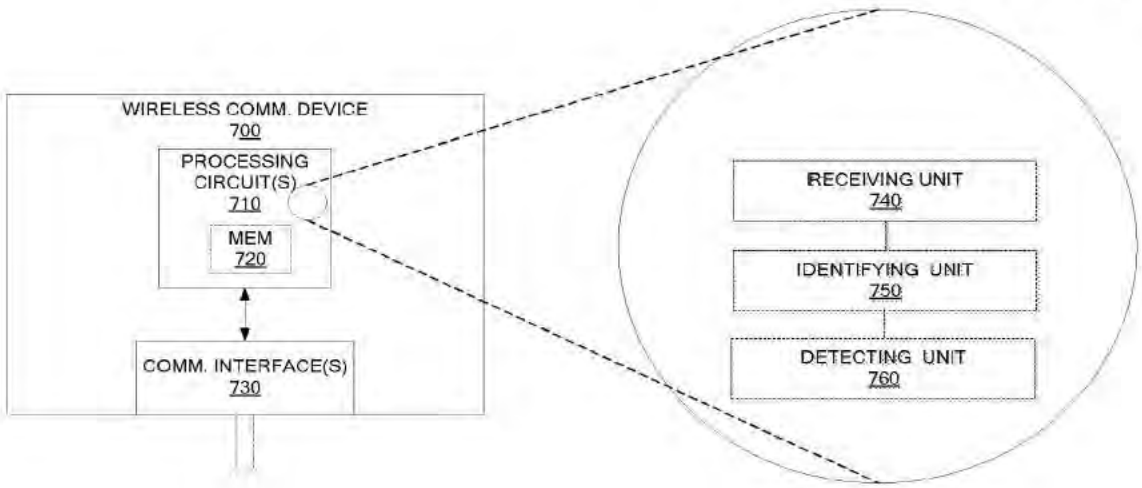

FIGURE 13

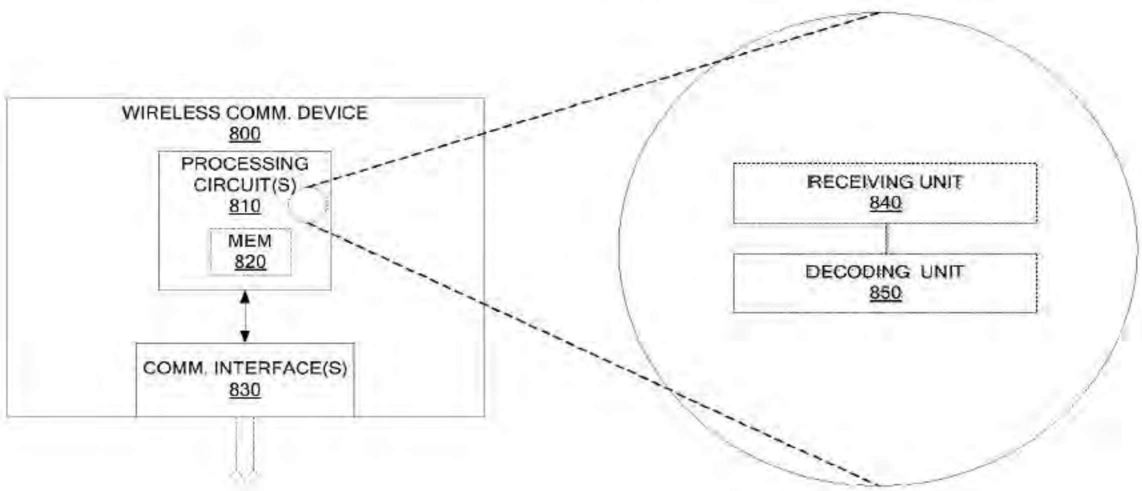

FIGURE 14

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DOCUMENT MADE AVAILABLE UNDER THE PATENT COOPERATION TREATY (PCT)

International application number:		**PCT/SE2016/050009**
International filing date:		**11 January 2016 (11.01.2016)**
Document type:		**Certified copy of priority document**
Document details:	Country/Office:	**US**
	Number:	**62/103,101**
	Filing date:	**14 January 2015 (14.01.2015)**
Date of receipt at the International Bureau:		**22 January 2016 (22.01.2016)**

Remark: Priority document submitted or transmitted to the International Bureau in compliance with Rule 17.1(a),(b) or (b-*bis*)

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0	**For receiving Office use only**	
0-1	International Application No.	PCT/SE2016/050009
0-2	International Filing Date	11 January 2016 (11.01.2016)
0-3	Name of receiving Office and "PCT International Application"	RO/SE

0-4	**Form PCT/RO/101 PCT Request**	
0-4-1	Prepared Using	PCT Online Filing Version 3.5.000.244e MT/FOP 20141031/0.20.5.20
0-5	**Petition** The undersigned requests that the present international application be processed according to the Patent Cooperation Treaty	
0-6	**Receiving Office (specified by the applicant)**	Swedish Patent and Registration Office (RO/SE)
0-7	**Applicant's or agent's file reference**	P45698WO1
I	**Title of Invention**	CODEBOOK SUBSET RESTRICTION SIGNALING
II	**Applicant**	
II-1	This person is	Applicant only
II-2	Applicant for	All designated States
II-4	Name	Telefonaktiebolaget L M Ericsson (publ)
II-5	Address	SE-164 83 Stockholm Sweden
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II-10	e-mail	patent.development@ericsson.com
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III-1	**Applicant and/or inventor**	
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III-5-3	Inventor for	All designated States
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IV-1	**Agent or common representative; or address for correspondence** The person identified below is hereby/ has been appointed to act on behalf of the applicant(s) before the competent International Authorities as:	Agent
IV-1-1	Name (LAST, First)	BOU FAICAL, Roger
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V-1	**The filing of this request constitutes under Rule 4.9(a), the designation of all Contracting States bound by the PCT on the international filing date, for the grant of every kind of protection available and, where applicable, for the grant of both regional and national patents.**	
VI-1	**Priority claim of earlier national application**	
VI-1-1	Filing date	14 January 2015 (14.01.2015)
VI-1-2	Number	62/103,101
VI-1-3	Country or Member of WTO	US
VI-2	**Priority document request** The International Bureau is requested to obtain from a digital library a certified copy of the earlier application(s) identified above as item(s), using, where applicable, the access code(s) indicated:	VI-1 Access code: 9403

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VII-1	**International Searching Authority Chosen**	European Patent Office (EPO) (ISA/EP)	
VIII	**Declarations**	Number of declarations	
VIII-1	Declaration as to the identity of the inventor	–	
VIII-2	Declaration as to the applicant's entitlement, as at the international filing date, to apply for and be granted a patent	–	
VIII-3	Declaration as to the applicant's entitlement, as at the international filing date, to claim the priority of the earlier application	–	
VIII-4	Declaration of inventorship (only for the purposes of the designation of the United States of America)	–	
VIII-5	Declaration as to non-prejudicial disclosures or exceptions to lack of novelty	–	
IX	**Check list**	Number of sheets	Electronic file(s) attached
IX-1	Request (including declaration sheets)	5	✓
IX-2	Description	30	✓
IX-3	Claims	8	✓
IX-4	Abstract	1	✓
IX-5	Drawings	14	✓
IX-7	TOTAL	58	
	Accompanying Items	Paper document(s) attached	Electronic file(s) attached
IX-8	Fee calculation sheet	–	✓
IX-19	Other	Pre-conversion archive	✓
IX-20	**Figure of the drawings which should accompany the abstract**		
IX-21	**Language of filing of the international application**	English	

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X-1	**Signature of applicant, agent or common representative**	/Roger Bou Faical/
X-1-1	Name (LAST, First)	BOU FAICAL, Roger
X-1-3	Capacity (if such capacity is not obvious from reading the request)	(Representative)

FOR RECEIVING OFFICE USE ONLY

10-1	**Date of actual receipt of the purported international application**	11 January 2016 (11.01.2016)
10-2	**Drawings:**	
10-2-1	Received	
10-2-2	Not received	
10-3	**Corrected date of actual receipt due to later but timely received papers or drawings completing the purported international application**	
10-4	**Date of timely receipt of the required corrections under PCT Article 11(2)**	
10-5	**International Searching Authority**	ISA/EP
10-6	**Transmittal of search copy delayed until search fee is paid**	

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PATENT COOPERATION TREATY

PCT/SE2016/050009

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF THE RECORDING OF A CHANGE

(PCT Rule 92*bis*.1 and Administrative Instructions, Section 422)

To:

BOU FAICAL, Roger
Ericsson AB
Patent Unit Kista RAN1
164 80 Stockholm
SUÈDE

Date of mailing *(day/month/year)* 20 May 2016 (20.05.2016)	
Applicant's or agent's file reference P45698WO1	**IMPORTANT NOTIFICATION**
International application No. PCT/SE2016/050009	International filing date *(day/month/year)* 11 January 2016 (11.01.2016)

1. The following indications appeared on record concerning:

☒ the applicant ☐ the inventor ☐ the agent ☐ the common representative

Name and Address	State of Nationality	State of Residence
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	Facsimile No.	
	E-mail address	

2. The International Bureau hereby notifies the applicant that the following change has been recorded concerning:

☐ the person ☐ the name ☐ the address ☐ the nationality ☐ the residence

Name and Address	State of Nationality	State of Residence
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	Facsimile No.	
	E-mail address ☐ Notifications by e-mail authorized	

3. Further observations, if necessary:
Please note that a change in "layout" of the applicant's name was acted upon.

4. A copy of this notification has been sent to:

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☐ the Authority(ies) specified for supplementary search
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(54) Title: CODEBOOK SUBSET RESTRICTION SIGNALING

(57) Abstract: A network node (10) signals to a wireless communication device (14) which precoders in a codebook are restricted from being used. The network node (10) in this regard generates codebook subset restriction signaling that, for each of one or more groups of precoders, jointly restricts the precoders in the group by restricting a certain component (e.g., a certain beam precoder) that the precoders in the group have in common. This signaling may be for instance rank-agnostic signaling that jointly restricts the precoders in a group without regard to the precoders' transmission rank. Regardless, the network node (10) sends the generated signaling to the wireless communication device (14).

CODEBOOK SUBSET RESTRICTION SIGNALING

RELATED APPLICATIONS

This application claims priority to U.S. Provisional patent Application Serial Number 62/103,101 filed January 14, 2015, the entire contents of which are incorporated herein by reference.

TECHNICAL FIELD

The present application relates generally to a network node and a wireless communication device for operation in a wireless communication system, and more particularly to the network node signaling to the wireless communication device which precoders in a codebook are restricted from being used.

BACKGROUND

The use of multiple antennas at the transmitter and/or the receiver of a wireless communication system can significantly boost the capacity and coverage of a wireless communication system. Such MIMO systems can exploit the spatial dimension of the communication channel. For example, several information-carrying signals can be sent in parallel using the transmit antennas and still be separated by signal processing at the receiver. By adapting the transmission to the current channel conditions, significant additional gains can be achieved. One form of adaptation is to dynamically, from one TTI to another, adjust the number of simultaneously transmitted information streams carrying signals to what the channel can support. This is commonly referred to as (transmission) rank adaptation. Precoding is another form of adaptation where the phases and amplitudes of the aforementioned signals are adjusted to better fit the current channel properties. The signals form a vector-valued signal and the adjustment can be thought of as multiplication by a precoder matrix. A common approach is to select the precoder matrix from a finite and indexed set, a so-called codebook. Such codebook-based precoding is an integral part of the LTE standard, as well as in many other wireless communication standards.

Codebook based precoding can be regarded as a form of channel quantization. A typical approach (c.f. LTE and MIMO HSDPA) is to let the receiver recommend a suitable precoder matrix to the transmitter by signaling the precoder matrix indicator (PMI) over a feedback link. To limit signaling overhead, it is generally important to keep the codebook size as small as possible if the feedback link has a limited capacity. This however needs to be balanced against the performance impact since with a larger codebook it is possible to better match the current channel conditions.

For example, in the LTE downlink, the user equipment (UE) reports the precoding matrix indicator (PMI) to the eNodeB either periodically on the physical uplink control channel (PUCCH) or aperiodic on the physical uplink shared channel (PUSCH). The former is a rather narrow bit pipe (e.g., using a few bits) where channel state information (CSI) feedback is reported in a semi-statically configured and periodic fashion. CSI feedback in this regard includes one or more channel quality indicators (CQIs), PMIs, and/or a transmission rank (e.g., indicating a number of transmission layers). On the other hand, reporting on PUSCH is dynamically triggered as part of the uplink grant. Thus, the eNodeB can schedule CSI transmissions in a dynamic fashion. In contrast to the PUCCH where the number of physical bits is currently limited to 20, the reports on PUSCH can be considerably larger. Thus, for feedback on PUCCH a small codebook size is desirable to keep the signaling overhead down. However, for feedback on PUSCH a larger codebook size is desirable to increase performance, since the capacity on the feedback channel is not as limited in this case.

The desired size of the codebook may also depend on the transmission scheme used. For example, a codebook used in multi-user multiple input multiple output (MU-MIMO) operation could benefit more from having a larger number of elements than a codebook used in single-user multiple input multiple output (SU-MIMO) operation. In the former case, a large spatial resolution is important to allow for sufficient UE separation.

A convenient way to support different codebook sizes is to use a large codebook with many elements by default and apply codebook subset restriction in the scenarios where a smaller codebook is beneficial. With codebook subset restriction, a subset of the precoders in the codebook is restricted so that the UE has a smaller set of possible precoders to choose from. This effectively reduces the size of the codebook implying that the search for the best PMI can be done on the smaller unrestricted set of precoders, thereby also reducing the UE computational requirements for this particular search.

Typically, the eNodeB would signal the codebook subset restriction to the UE by means of a bitmap in an a dedicated message part of the AntennaInfo information element (see the RRC specification, TS 36.331), one bit for each precoder in the codebook, where a 1 would indicate that the precoder is restricted (meaning that the UE is not allowed to choose and report said precoder). Thus, for a codebook with N elements, a bitmap of length N would be used to signal the codebook subset restriction. This allows for full flexibility for the eNodeB to restrict every possible subset of the codebook. There are thus 2^N possible codebook subset restriction configurations.

For large antenna arrays with many antenna elements, the effective beams become narrow and a codebook containing many precoders is required for the intended coverage area. Furthermore, for two-dimensional antenna arrays, the codebook size increases quadratically since the precoders in the codebook need to span two dimensions, typically the horizontal and vertical domain. Thus, the codebook size (i.e. the total number of possible precoding matrices

W) can be very large. Signaling a codebook subset restriction in the conventional way by means of a bitmap with one bit for every precoder can thus impose a large overhead, especially if the codebook subset restriction (CSR) is frequently updated or if there are many users served by the cell which each has to receive the CSR.

SUMMARY

One or more embodiments herein include a method implemented by a network node for signaling to a wireless communication device which precoders in a codebook are restricted from being used. The method comprises generating codebook subset restriction signaling that, for each of one or more groups of precoders, jointly restricts the precoders in the group by restricting a certain component that the precoders in the group have in common. The method further comprises sending the generated signaling from the network node to the wireless communication device.

Embodiments herein also correspondingly include a method implemented by a wireless communication device for decoding signaling from a network node indicating which precoders in a codebook are restricted from being used. The method comprises receiving codebook subset restriction signaling that, for each of one or more groups of precoders, jointly restricts the precoders in the group by restricting a certain component that the precoders in the group have in common. The method further comprises decoding the received signaling as jointly restricting precoders in each of the one or more groups of precoders.

In some embodiments, the codebook subset restriction signaling is rank-agnostic signaling that jointly restricts the precoders in a group without regard to the precoders' transmission rank.

In some embodiments, the certain component comprises a beam precoder. In some embodiments, for example, a beam precoder is a Kronecker product of different beamforming vectors associated with different dimensions of a multi-dimensional antenna array. In this case, the different beamforming vectors may comprise Discrete Fourier Transform (DFT) vectors.

In other embodiments where the certain component comprises a beam precoder, a beam precoder is a beamforming vector used to transmit on a particular layer of a multi-layer transmission. Different scaled versions of that beamforming vector are transmitted on different polarizations.

In still other such embodiments, a beam precoder is a beamforming vector used to transmit on: multiple different layers of a multi-layer transmission; multiple different layers of a multi-layer transmission, wherein the layers are sent on orthogonal polarizations; or a particular layer and on a particular polarization.

In some embodiments, a precoder comprising one or more beam precoders is restricted if at least one of its one or more beam precoders is restricted.

In any of these embodiments, the codebook subset restriction signaling may comprise a bitmap, with different bits in the bitmap respectively dedicated to indicating whether or not different beam precoders are restricted from being used.

Alternatively or additionally, a beam precoder may be a Kronecker product of first and second beamforming vectors with first and second indices. In this case, the first and second beamforming vectors may be associated with different dimensions of a multi-dimensional antenna array, and the codebook subset restriction signaling may jointly restrict the precoders in a group of precoders that have the same pair of values for the first and second indices.

In some embodiments, each precoder comprises one or more beam precoders. In some of these embodiments, each beam precoder comprises multiple different components corresponding to different dimensions of a multi-dimensional antenna array. The certain component in this case may comprise a component of a beam precoder.

In some embodiments, the codebook subset restriction signaling jointly restricts the precoders in a group of precoders that transmit at least in part towards a certain angular pointing direction, by restricting a certain component which has that angular pointing direction.

Embodiments herein also include another method implemented by a network node for signaling to a wireless communication device which precoders in a codebook are restricted from being used. The method comprises a number of steps for each of one or more groups of precoders in the codebook. These steps include identifying one or more reference configurations for the group. Each reference configuration is one of different possible configurations that restrict different subgroups of precoders in the group from being used. The steps also include identifying, from the different possible configurations for the group, an actual configuration to be signaled for the group. The steps also include generating signaling to indicate the actual configuration for the group, by generating the signaling as a bit pattern whose length depends on (i) whether the actual configuration matches one of the one or more reference configurations and/or (ii) which reference configuration the actual configuration matches. The method further comprises sending the generated signaling to the wireless communication device.

Embodiments herein further include another corresponding method implemented by a wireless communication device for decoding signaling from a network node indicating which precoders in a codebook are restricted from being used. The method includes receiving signaling from the network node. The method also entails a number of steps for each of one or more groups of precoders in the codebook. These steps include identifying one or more reference configurations for the group. Each reference configuration is one of different possible configurations that restrict different subgroups of precoders in the group from being used. The steps further include identifying a bit pattern defined for signaling each reference configuration, and a length of that bit pattern. The steps also include detecting an actual configuration signaled for the group, by detecting in the signaling a bit pattern whose length depends on (i) whether the actual configuration matches one of the one or more reference configurations and/or (ii) which reference configuration the actual configuration matches.

In some embodiments, the signaling is a short bit pattern when the actual configuration matches any one of the one or more reference configurations and is a long bit pattern when the actual configuration does not match any of the one or more reference configurations. A long bit pattern has more bits than a short bit pattern. In this case, the one or more reference configurations for at least one of the one or more groups may comprise a single reference configuration, and different long bit patterns may be respectively defined for signaling different configurations other than the single reference configuration. Alternatively or additionally, a long bit pattern defined for signaling the actual configuration for the group may comprise: (i) a non-reference bit pattern defined for signaling that the actual configuration does not match a reference configuration for the group; and (ii) a bitmap comprising different bits respectively dedicated to indicating whether different precoders in the group are restricted from being used.

In some embodiments, the one or more reference configurations for at least one of the one or more groups comprise multiple reference configurations. In this case, when the actual configuration matches a particular one of the multiple reference configurations, the signaling is a bit pattern whose length is shorter than that of a bit pattern generated when the actual configuration matches a different one of the multiple reference configurations.

In some embodiments, the one or more reference configurations for a group each have an actual or assumed higher probability of being signaled than any other possible configuration that is not one of the one or more reference configurations.

In some embodiments, the method is performed for multiple different groups that respectively include different portions of the precoders in the codebook. In this case, the signaling indicates the actual configurations for the groups in a defined order. The one or more reference configurations for each group comprises a single reference configuration, and the single reference configuration for any given group is the actual configuration, if any, signaled immediately before that of the given group.

In some embodiments, the codebook is a Kronecker codebook defined for a multi-dimensional antenna array and comprises different precoders indexed by different possible values of a single index parameter. In this case, the different possible values of the single index parameter are divided into different clusters of consecutively ordered values, and precoders in different ones of the one or more groups are respectively indexed by the different clusters of consecutively ordered values.

In some embodiments, the codebook is a Kronecker codebook defined for a multi-dimensional antenna array and comprises different precoders indexed by different pairs of possible values for a first-dimension index parameter and a second-dimension index parameter. In this case, precoders in each of the one or more groups are indexed by pairs that have the same value for either the first-dimension index parameter or the second-dimension index parameter.

Embodiments herein further include corresponding apparatus and computer program products.

In at least some embodiments, signaling a codebook subset restriction in this way advantageously lowers the signaling overhead imposed by transmitting the codebook subset restriction, while still allowing for flexibility in configuring different codebook subset restrictions.

Embodiments herein therefore generally include methods to reduce the number of bits required for signaling a codebook subset restriction configuration to a wireless communication device. The methods in one or more of these embodiments do so by:

Utilizing an explicit or implicit assumption about which sets of precoders are more likely to be restricted, and/or associating a group of precoders with a single codebook subset restriction bit.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a logic flow diagram indicating codebook subset restriction (CSR) signaling between a network node and a wireless communication device according to one or more embodiments.

Figure 2 is a logic flow diagram of a method implemented by a network node for signaling to a wireless communication device which precoders in a codebook are restricted from being used, according to some embodiments.

Figure 3 is a block diagram of a two-dimensional antenna array of cross-polarized antenna elements according to some embodiments.

Figure 4 is a graph illustrating the angular pointing directions of precoders in a codebook according to some embodiments.

Figure 5 is a logic flow diagram of a method implemented by a network node for signaling to a wireless communication device which precoders in a codebook are restricted from being used, according to other embodiments.

Figure 6 is a block diagram of an exemplary codebook according to some embodiments.

Figure 7 is a graph illustrating the angular pointing directions of precoders in a codebook according to other embodiments.

Figure 8 is a block diagram of precoder groupings according to some embodiments.

Figure 9 is a logic flow diagram of a method implemented by a wireless communication device for decoding signaling from a network node indicating which precoders in a codebook are restricted from being used, according to some embodiments.

Figure 10 is a logic flow diagram of a method implemented by a wireless communication device for decoding signaling from a network node indicating which precoders in a codebook are restricted from being used, according to other embodiments.

Figure 11 is a block diagram of a network node according to some embodiments.

Figure 12 is a block diagram of a network node according to other embodiments.

Figure 13 is a block diagram of a wireless communication device according to some embodiments.

Figure 14 is a block diagram of a wireless communication device according to other embodiments.

DETAILED DESCRIPTION

According to the flowchart of Figure 1, a network node 10 in a wireless communication network (e.g., an eNB in the network) signals a codebook subset restriction (CSR) configuration 12 to a wireless communication device 14 (e.g., a UE). The device 14 then sends a channel state information (CSI) report 16 back to the network. This CSI report 16 suggests which of different possible precoders in a codebook the network should use for transmitting to the device 14, but the CSI report 16 is restricted in the sense that there is a subset of precoders that cannot be reported by the device 14; that is, all precoders in the codebook cannot be selected and reported by the device 14. This restriction is defined by the signaled CSR configuration 12.

In more detail, for a precoder codebook X, consisting of N precoders, there are 2^N possible codebook subset restriction configurations since each precoder can individually either be allowed or restricted (a restricted configuration is not allowed to be used). Each configuration can be represented by a bitmap of N bits, where each bit corresponds to a certain precoder and the value of the bit then indicates whether the precoder is restricted or not. If each of the 2^N configurations is equiprobable and independent, this is the optimal representation of a codebook subset restriction configuration with respect to the expected length (in bits) of the representation and it provides full flexibility.

However, embodiments herein recognize that, if certain configurations are more likely to be used than others, and/or if the restriction of one precoder is highly correlated to the restriction of another precoder, then this signaling leads to unnecessarily high signaling overhead. One or more embodiments herein include methods to reduce this signaling overhead; that is, reduce the number of bits required for signaling a codebook subset restriction configuration to a wireless communication device 14 from the network. In some embodiments, for example, the methods utilize an implicit assumption about which sets of precoders are more likely to be restricted or which sets of precoders are likely to be jointly restricted.

According to one embodiment shown in Figure 2, for example, a method is implemented by a network node 10 (e.g., a base station) for signaling to a wireless communication device 14 which precoders in a codebook are restricted from being used. For each of one or more groups of precoders in the codebook, the method includes identifying one or more reference configurations for the group (Block 110). Each reference configuration is one of different possible configurations that restrict different subgroups of precoders in the group from being used. One of the reference configurations for a group may be for instance whichever one of the different possible configurations has the maximum probability of being signaled, e.g., as predicted or estimated based on empirical observations or implicit assumptions. Regardless, the method further includes identifying, from the different possible configurations for the group, the actual configuration to be signaled for the group (Block 120).

The method also includes generating signaling to indicate the actual configuration for the group (Block 130). This entails generating the signaling as a bit pattern whose length depends on (i) whether the actual configuration matches one of the one or more reference configurations; and/or (ii) which reference configuration the actual configuration matches. In some embodiments, for example, when the actual configuration matches any reference configuration, the bit pattern's length is shorter than when the actual configuration does not match any reference configuration. In other embodiments, when the actual configuration matches a particular one of multiple reference configurations, the bit pattern's length is shorter than when the actual configuration matches a different one of the reference configurations. Regardless, this process (Blocks 110-130) is repeated for each of one or more groups of precoders in the codebook (Blocks 100, 140, and 150). Finally, the method includes sending the generated signaling to the wireless communication device 14 (Block 160).

This approach may in some sense be viewed as a sort of compression algorithm for CSR signaling. Indeed, the approach advantageously reduces the signaling overhead when, over the course of a given time period, the overhead savings realized by signaling bit patterns with relatively shorter lengths outweighs the overhead costs imposed by signaling bit patterns with relatively longer lengths. Depending on the relative lengths of the bit patterns, then, the approach may for instance reduce signaling overhead when the one or more reference configurations (or particular ones of the one or more reference configurations) are signaled more often than not.

In at least some embodiments, therefore, a reference configuration has a higher likelihood or probability of being signaled than any other possible configurations that are not reference configurations. For example, the one or more reference configurations for a group may include whichever one(s) of the different possible configurations for the group have the highest probability of being signaled. Different reference configurations that have different probabilities of being signaled may be represented with bit patterns of different lengths, where reference configurations with higher probabilities are represented with bit patterns of shorter lengths. That is, certain configurations that are deemed more probable may be represented with a fewer number of bits, while other configurations, that are deemed less probable to be used, may be represented with a larger number of bits.

In some embodiments, the one or more reference configurations may be predefined to be particular one(s) of the possible configurations, e.g., based on an (implicit) assumption that the particular configuration(s) have the highest probability of being signaled. For example, an implicit assumption is made on how the network is likely to be configured. Hence, here certain configurations are considered more likely than others but there are no actual probability values estimated for the different configurations.

In other embodiments, though, the network node 10 determines signaling probabilities of different configurations, e.g., based on empirical observations and compares those probabilities to identify the configuration(s) with the highest probability. In one embodiment for example signaling probabilities are estimated through logging of network data. Hence, here it may be possible to estimate actual probabilities for the different configurations. In general, therefore, the knowledge on "how likely" a certain configuration is may be obtained in many ways.

In some embodiments, only a single reference configuration is defined for a group. In this case, the signaling is generated as a short bit pattern when the actual configuration matches the reference configuration and as a long bit pattern when the actual configuration does not match the reference configuration. Different long bit patterns in this regard are respectively defined for signaling different configurations (other than the reference configuration, for which the short bit pattern is defined for signaling). A long bit pattern of course has more bits than a short bit pattern (e.g., N bits vs. 1 bit).

In other embodiments, multiple reference configurations are defined for a group. In this case, the signaling may be generated as bit patterns that have different lengths when the actual configuration matches different reference configurations. These lengths may correspond to how likely it is that the reference configurations will be signaled. The bit pattern's length may be shortest when the actual configuration matches a particular one of the reference configurations (e.g., the one with the maximum probability of being signaled), may be next shortest when the actual configuration matches a different reference configuration (e.g., the one with the next highest signaling probability), and may be longest when the actual configuration does not match any of the reference configurations.

In some embodiments, bit patterns signaling non-reference configurations are encoded as a combination of a so-called "non-reference bit pattern" and a "bitmap." The non-reference bit pattern is defined for signaling that the actual configuration for the group does not match any reference configuration for the group. The non-reference bit pattern may for instance be the complement of a bit pattern defined for signaling a reference configuration. For example, when only a single reference configuration is defined for a group, the bit pattern signaling that reference configuration may simply be a single bit with a value of "1", whereas the non-reference bit pattern may be a single bit with a value of "0". Regardless, the bitmap portion of the bit pattern comprises different bits respectively dedicated to indicating whether different precoders in the group are restricted from being used.

In at least some embodiments, the method is performed for only one group. This single group in one embodiment includes all precoders in the codebook.

In another embodiment, of course, the single group includes only a portion of the precoders in the codebook, such that the signaling approach is adopted for only this portion, while other signaling approaches (e.g., the conventional bitmap) is adopted for other portions.

In other embodiments, the method is performed for multiple different groups that respectively include different portions of the precoders in the codebook. In one such embodiment, the signaling indicates the actual configurations for the groups in a defined order. In one embodiment, the one or more reference configurations for any given group includes the actual configuration, if any, signaled immediately before that of the given group (according to the defined order).

Consider an example with an arbitrary codebook of size N, where the single group includes all N precoders. A certain configuration out of the 2^N possible codebook subset restriction configurations for the single group is deemed more probable. This configuration is represented by a single bit, '1'. The other $2^N - 1$ configurations are represented by a '0', followed by a bitmap of size N. One of the configurations is then represented by 1 bit, while the other configurations are represented by $N + 1$ bits. Since the configuration represented by one bit is more frequently signaled, according to the assumption, the average number of bits required to convey the codebook subset restriction may be much less than N.

However, if the assumption that one of the possible codebook subset restriction configurations was more likely than the others was incorrect for the actual usage of codebook subset restriction configurations, the average number of bits required to convey a codebook subset restriction to a UE may be larger than N bits. One or more embodiments herein therefore aim to choose the representations of the 2^N configurations well. Various methods may represent the 2^N configurations differently depending on which sets of precoders are more likely to be restricted.

Consider for example embodiments where the codebook is defined for a multi-dimensional (e.g., two-dimensional) antenna array. Such antenna arrays may be (partly) described by the number of antenna columns corresponding to the horizontal dimension M_h, the number of antenna rows corresponding to the vertical dimension M_v and the number of dimensions corresponding to different polarizations M_p The total number of antennas is thus $M = M_h M_v M_p$. It should be pointed out that the concept of an antenna is non-limiting in the sense that it can refer to any virtualization (e.g., linear mapping) of the physical antenna elements. For example, pairs of physical sub-elements could be fed the same signal, and hence share the same virtualized antenna port.

An example of a 4x4 array with cross-polarized antenna elements is illustrated in Figure 3. Specifically, Figure 3 shows a two-dimensional antenna array of cross-polarized antenna elements ($M_P = 2$), with $M_h = 4$ horizontal antenna elements and $M_v = 4$ vertical antenna elements, assuming one antenna element corresponds to one antenna port.

Precoding may be interpreted as multiplying the signal with different beamforming weights for each antenna prior to transmission. A typical approach is to tailor the precoder to the antenna form factor, i.e. taking into account M_h, M_v and M_p when designing the precoder codebook.

According to some embodiments, a precoder codebook is tailored for 2D antenna arrays by combining precoders tailored for a horizontal array and a vertical array respectively by means of a Kronecker product. This means that (at least part of) the precoder can be described as a function of

$$W_H \otimes W_V$$

where W_H is a horizontal precoder taken from a (sub)-codebook $\boldsymbol{X}_H$ containing N_H codewords and similarly W_V is a vertical precoder taken from a (sub)-codebook $\boldsymbol{X}_V$ containing N_V codewords. The joint codebook, denoted $\boldsymbol{X}_H \otimes \boldsymbol{X}_V$, thus contains $N_H \cdot N_V$ codewords. The elements of $\boldsymbol{X}_H$ are indexed with $k = 0, \ldots, N_H - 1$, the elements of $\boldsymbol{X}_V$ are indexed with $l = 0, \ldots, N_V - 1$ and the elements of the joint codebook $\boldsymbol{X}_H \otimes \boldsymbol{X}_V$ are indexed with $m = N_V \cdot k + l$ meaning that $m = 0, \ldots, N_H \cdot N_V - 1$.

In some embodiments, for example, the (sub)-codebooks of the Kronecker codebook consist of DFT-precoders. In this case, the horizontal codebook can be expressed as $\boldsymbol{X}_H^k = \left[1 \;\; e^{j2\pi\frac{1k+\Delta_h}{M_h Q_h}} \;\; \cdots \;\; e^{j2\pi\frac{(M_h-1)k+\Delta_h}{M_h Q_h}}\right]^T$, $k = 0, \ldots, M_h Q_h - 1$, where Q_h is an integer horizontal oversampling factor and Δ_h can take on value in the interval 0 to 1 so as to "shift" the beam pattern (Δ_h =0.5 could be an interesting value for creating symmetry of beams with respect to the broadside of an array). And the vertical codebook can be expressed as

$\boldsymbol{X}_V^l = \left[1 \;\; e^{j2\pi\frac{1l+\Delta_v}{M_v Q_v}} \;\; \cdots \;\; e^{j2\pi\frac{(M_v-1)l+\Delta_v}{M_v Q_v}}\right]^T$, $l = 0, \ldots, M_v Q_v - 1$, where $Q_v$is an integer vertical oversampling factor and Δ_v is similarly defined as above.

It should be pointed out that a precoder codebook may be defined in several ways. For example, the above mentioned Kronecker codebook may be interpreted as one codebook indexed with a single PMI m. Alternatively, it may be interpreted as a single codebook indexed with two PMIs k and l. It may also be interpreted as two separate codebooks, indexed with k and l respectivly. Further, the Kronecker codebook discussed above may only describe a part of the precoder, i.e. the precoder may be a function of other parameters as well. In a such example, the precoder is a function also of another PMI n. Again, this can be interpreted as three separate codebooks with indices k, l and n respectively, or two separate codebooks with indices $m = N_V \cdot k + l$ and n respectivly. It may also be interpreted as a single joint codebook with a joint PMI. Embodiments herein should be considered agnostic with respect to how a codebook is defined.

With this understanding, the codebook at issue in Figure 2 may be a Kronecker codebook that comprises different precoders indexed (at least in part) by different possible values of a single index parameter (e.g., index parameter $m = 0, \ldots, N_H \cdot N_V - 1$). In this case, the different possible values of the single index parameter are divided into different clusters of consecutively ordered values. And precoders in the different groups are respectively indexed (at least in part) by the different clusters of consecutively ordered values. For example, precoders indexed by the cluster $m = 0, \ldots m1$ belong to a first group, precoders indexed by the cluster $m = m2, \ldots m3$ belong to a second group, precoders indexed by the cluster $m = m4, \ldots m5$ belong to a third group, and so on. As an even more specific example, one or more embodiments exploit the Kronecker structure of the precoder by mapping the index m to indices k and l as $m = N_v k + l$ and grouping the precoders such that m = 0,…,Nv-1 is the first group, m= Nv,…,2Nv-1 is the second group , etc.

In another embodiment, by contrast, the Kronecker codebook comprises different precoders indexed (at least in part) by different pairs of possible values for a first-dimension index parameter (e.g., $k = 0, \ldots, N_H - 1$) and a second-dimension index parameter (e.g., $l = 0, \ldots, N_V - 1$). In this case, precoders in each of the different groups are indexed (at least in part) by pairs (k, l) that have the same value for the first-dimension index parameter k and/or the second-dimension index parameter l.

Two different embodiments in this regard, referred to as a "similar rows embodiment" and a "similar columns embodiment", will now be illustrated in the context of a Kronecker codebook and where only a single reference configuration is defined for a group. The Kronecker codebook in this example consists of precoders with different angular directions, spanning a two-dimensional angular area as seen from the transmitter. An important use case for codebook subset restriction in such an embodiment may be to restrict precoders in a certain angular area or angle interval, e.g. corresponding to a direction where a user hotspot of an adjacent cell is located. The eNodeB would then reduce interference to said adjacent cell and particular the hotspot area if precoders corresponding to beams pointing at that direction were restricted. This is beneficial from a system capacity perspective.

In the following, consider the specific example where codebook subset restriction is used on a Kronecker codebook in order to understand how different embodiments can be used to reduce the signaling overhead. In this scenario, a 4x4 antenna array with a mechanical downtilt of $18°$ is used. The Kronecker codebook consists of 8 vertical and 8 horizontal precoders, i.e. $N_H = N_V = 8$. The angular pointing directions of the precoders in the codebook are illustrated in Figure 4.

Codebook subset restriction is applied to restrict beams with pointing directions in the zenith interval $[85°, 95°]$ (illustrated with dotted lines). That is, codebook subset restriction is applied in the angular interval $85° < \theta < 95°$, meaning that the precoders with indices $(k, l) = (0,4), (3,5), (4,5), (7,4)$ are restricted. These restricted beams are illustrated with an 'o' while the unrestricted beams are illustrated with an 'x'. The beam index k in the horizontal codebook and l in the vertical codebook is written next to the beams as (k, l). If this configuration of codebook