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Ding et al.

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(54) **APPARATUS AND METHOD FOR CHANNEL ESTIMATION USING TRAINING SIGNALS WITH REDUCED SIGNAL OVERHEAD**

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H04L 1/02 (2006.01)

(52) **U.S. Cl.** **375/347**

(58) **Field of Classification Search** 375/347
See application file for complete search history.

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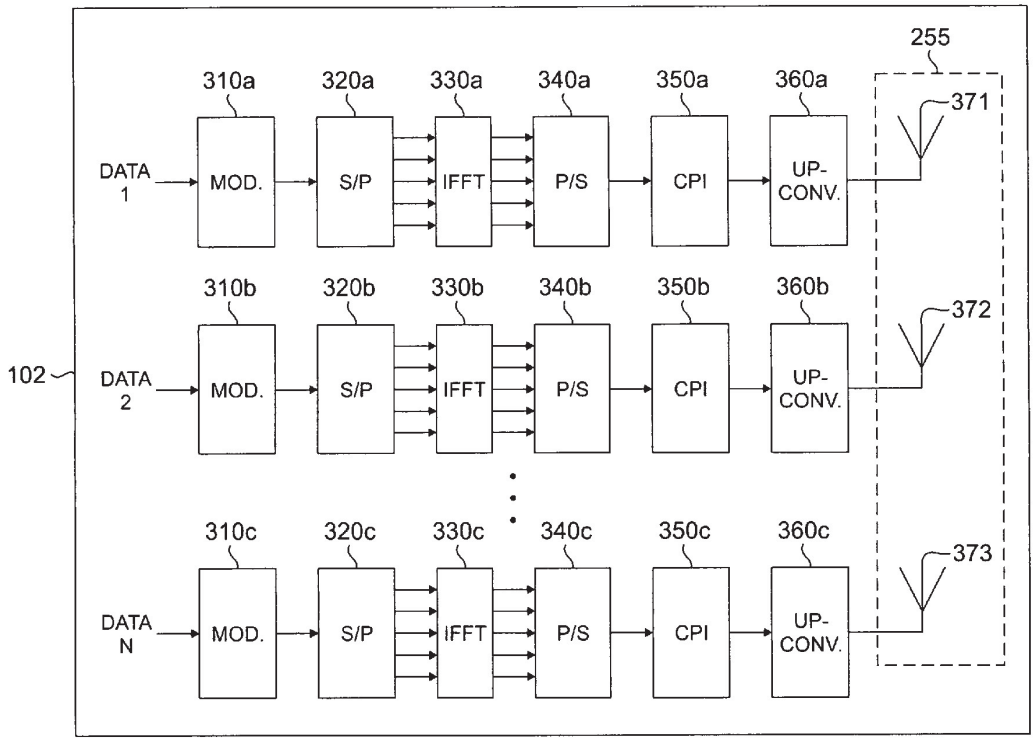
(57) **ABSTRACT**

A base station comprising an antenna array including M antennas for transmitting data to a plurality of subscriber stations. The base station generates a first pilot signal preamble by adding a first cyclic prefix to a first pilot signal sequence and generates a second pilot signal preamble by adding a second cyclic prefix to a second pilot signal sequence. The second pilot signal sequence is a circularly shifted copy of the first pilot signal sequence. The first pilot signal preamble is transmitted from a first antenna and the second pilot signal preamble is transmitted from a second antenna concurrently with transmission of the first preamble.

20 Claims, 5 Drawing Sheets



ZTE/SAMSUNG/HTC 1006-0001

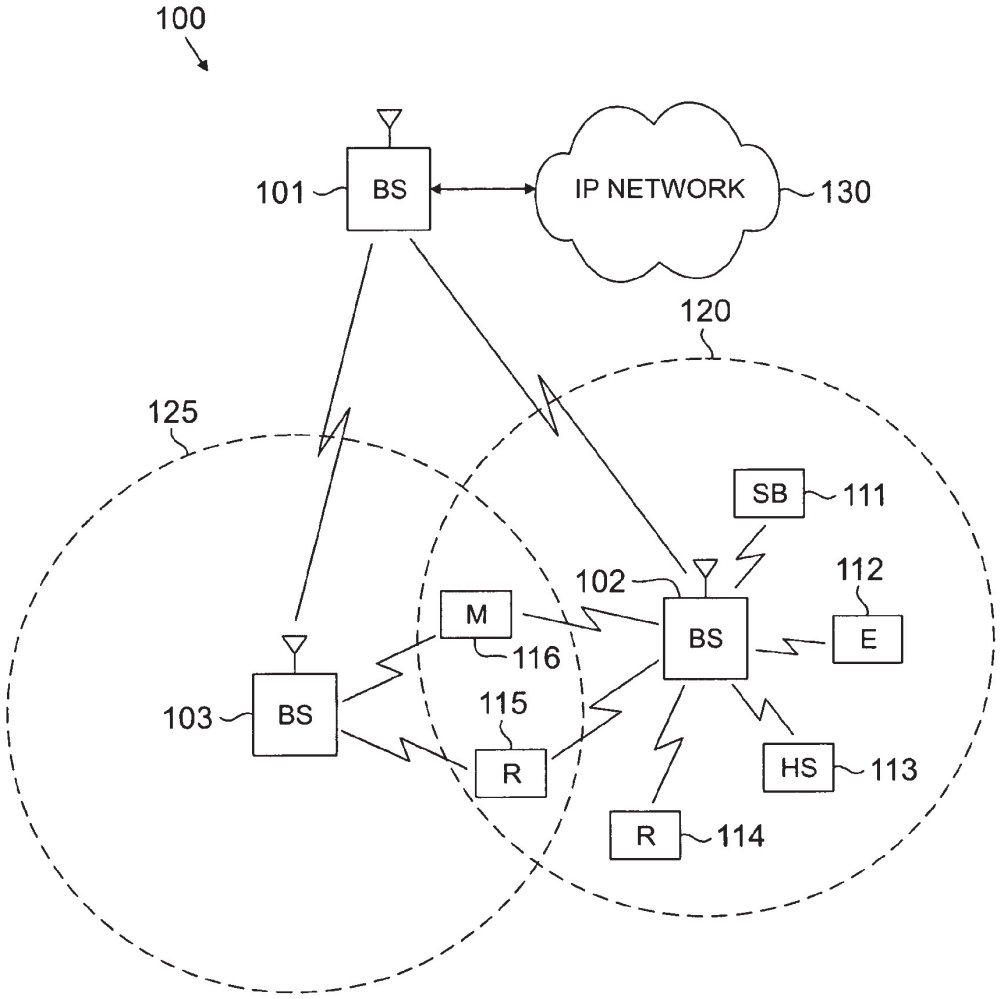

100
101
BS
IP NETWORK
130
120
125
SB
111
102
112
M
BS
E
116
103
BS
115
R
HS
113
R
114

FIG. 1

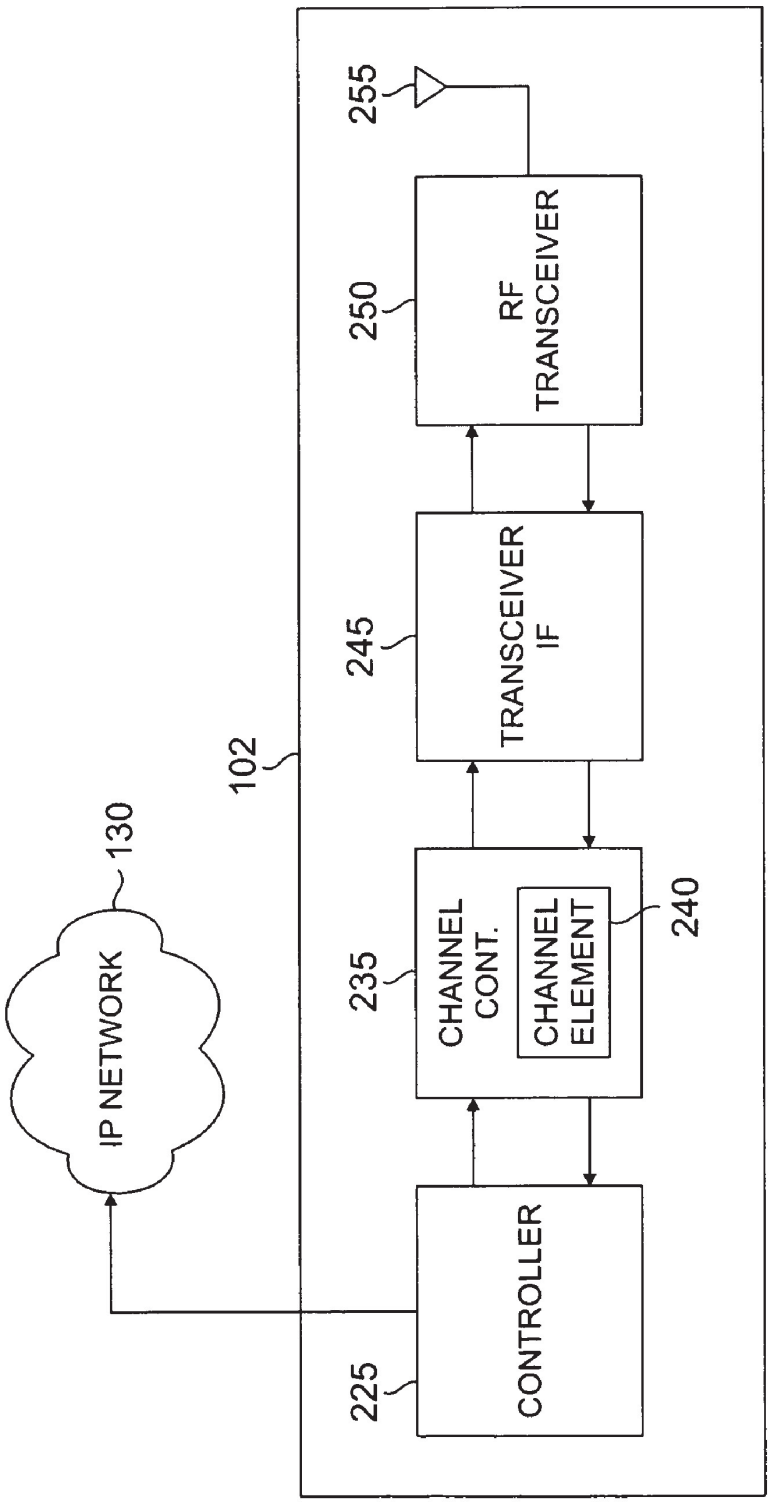

255
250
RF TRANSCEIVER
245
TRANSCEIVER IF
102
130
IP NETWORK
235
CHANNEL CONT.
CHANNEL ELEMENT
240
225
CONTROLLER

FIG. 2

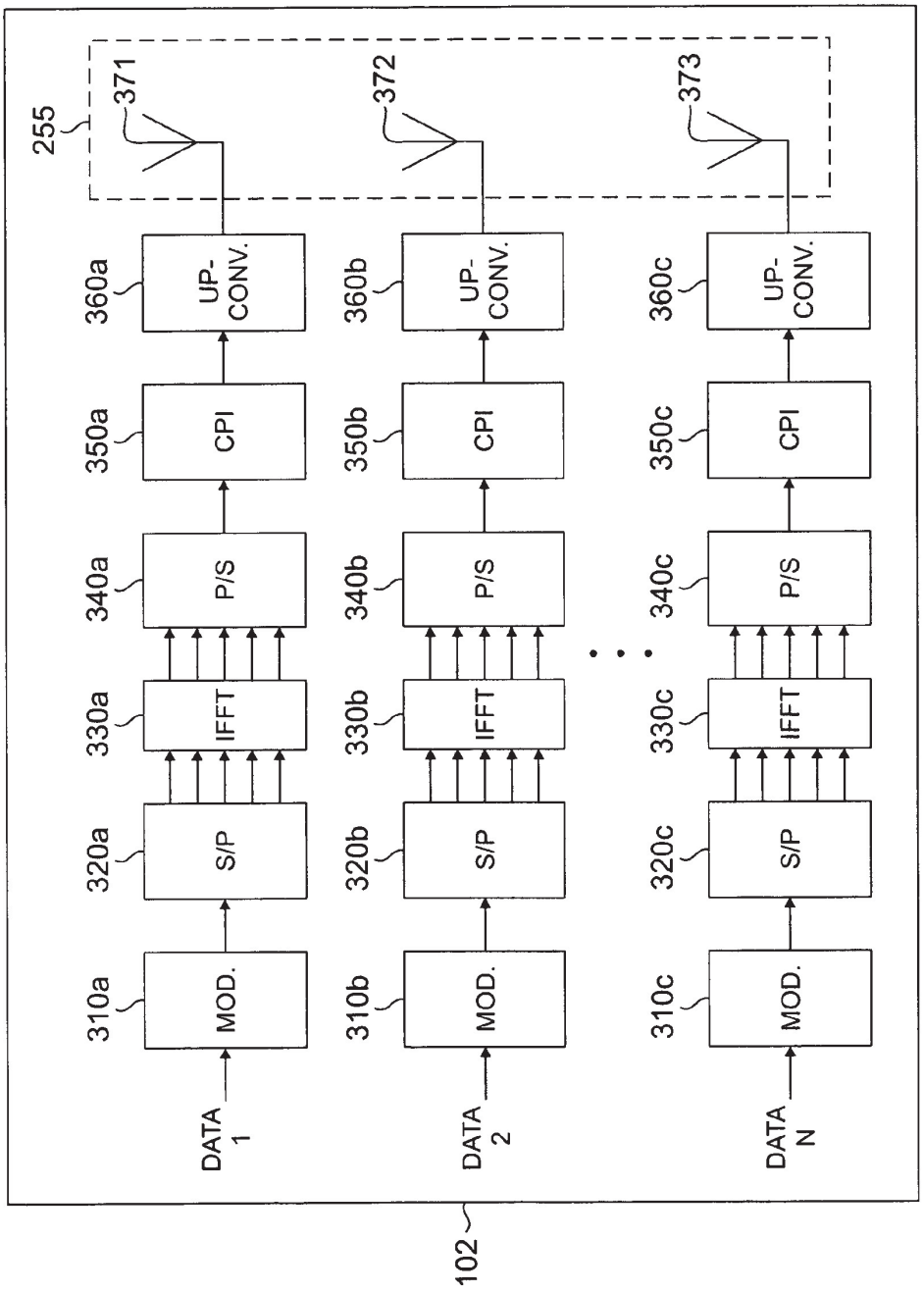

102
255
371
372
373
360a
360b
360c
UP-CONV.
350a
350b
350c
CPI
340a
340b
340c
P/S
330a
330b
330c
IFFT
320a
320b
320c
S/P
310a
310b
310c
MOD.
DATA 1
DATA 2
DATA N

FIG. 3

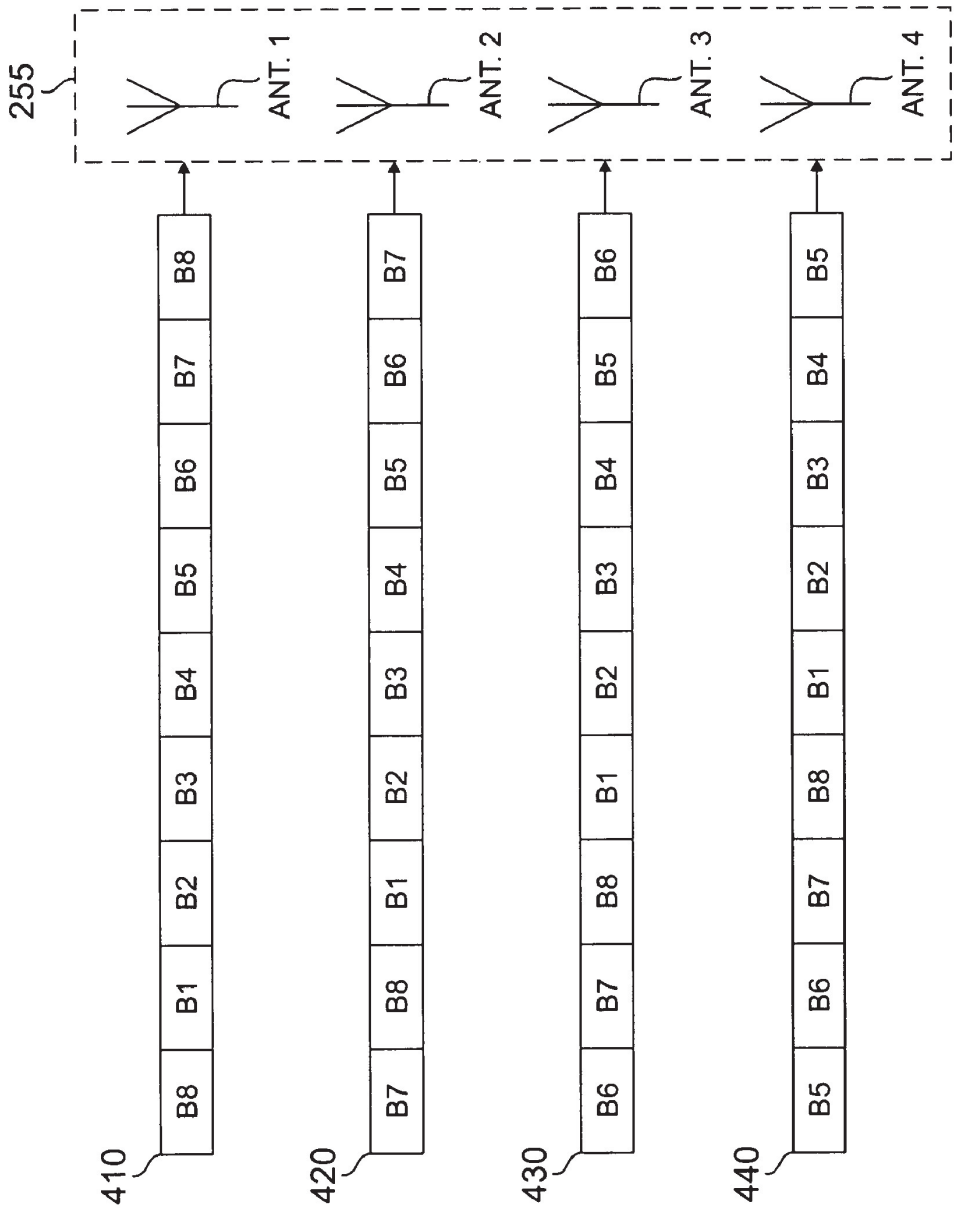

255
ANT. 1
ANT. 2
ANT. 3
ANT. 4
410
B8 B1 B2 B3 B4 B5 B6 B7 B8
420
B7 B8 B1 B2 B3 B4 B5 B6 B7
430
B6 B7 B8 B1 B2 B3 B4 B5 B6
440
B5 B6 B7 B8 B1 B2 B3 B4 B5

FIG. 4

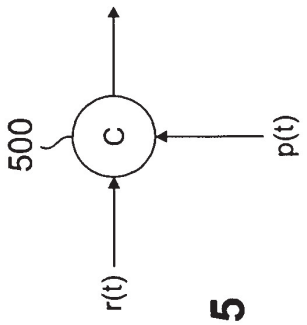


FIG. 5

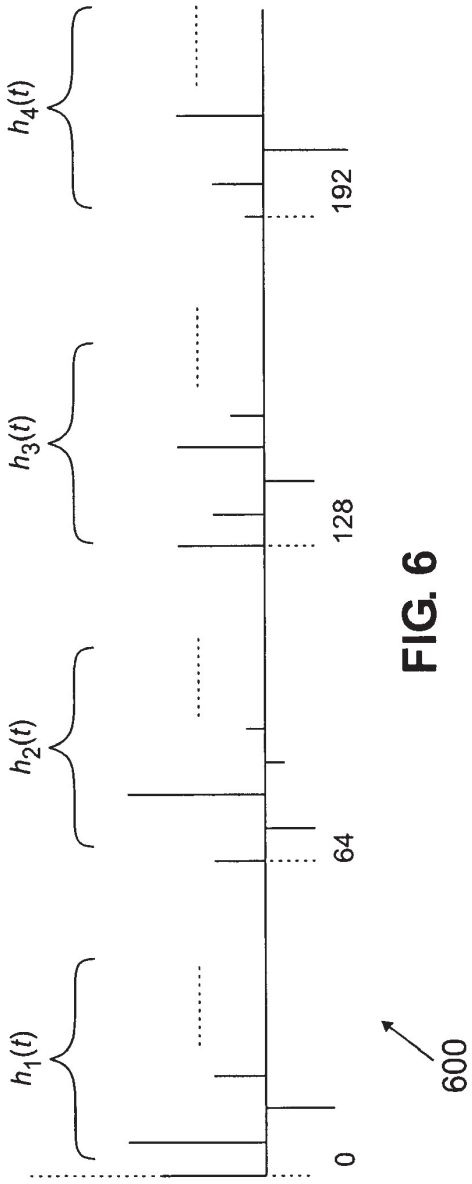


FIG. 6

APPARATUS AND METHOD FOR CHANNEL ESTIMATION USING TRAINING SIGNALS WITH REDUCED SIGNAL OVERHEAD

TECHNICAL FIELD OF THE INVENTION

The present application relates generally to wireless communications and, more specifically, to a channel estimation technique having reduced signaling overhead for use in multiple-input, multiple-output (MIMO) systems.

BACKGROUND OF THE INVENTION

An increasing number of wireless networks are implemented as multiple-input, multiple-output (MIMO) systems that use multiple antennas to communicate with subscriber stations (also called mobile stations, mobile terminals, and the like). For example, MIMO antenna systems are used in code division multiple access (CDMA) networks, time division multiplexing (TDM) networks, time division multiple access (TDMA) networks, orthogonal frequency division multiplexing (OFDM) networks, orthogonal frequency division multiple access (OFDMA) networks, and others. In order to maximize throughput, MIMO networks use a variety of channel estimation techniques to measure the transmission channels between base stations of the wireless networks and mobile devices.

For example, a MIMO base station may transmit a first pilot signal from a first antenna and a second pilot signal from a second antenna. A subscriber station receives both pilot signals and uses each pilot signal to perform channel estimation for each antenna. The symbols of the pilot signals are transmitted on orthogonal subcarriers to prevent the pilot signals from interfering with each other. No data symbols are transmitted on the subcarriers of the pilot signals. If more than two antennas are used, each antenna transmits a separate pilot signal on a dedicated subcarrier that is orthogonal to the other pilot signal subcarriers. The drawback to this method is that a large amount of signaling overhead is used for channel estimation. This wastes bandwidth and reduces system capacity.

Besides achieving pilot orthogonality in the dimension of the subcarriers, the pilot orthogonality may also achieved in the dimension of time. A MIMO base station may transmit separate pilot signals from different antennas using time multiplexing to separate the pilot signals. For example, during a first transmit time, the base station may transmit a first pilot signal from a first antenna. Then, during a second transmit time, the base station may transmit a second pilot signal from a second antenna. If more than two antennas are used, each antenna transmits a separate pilot signal during a separate transmit time. The drawback to this method is that more time slots are needed for pilot signals, thereby reducing the number of time slots available for transmitting user data. As before, this reduces system capacity.

In some CDMA systems, multiple pilot signals are transmitted simultaneously from multiple antennas, but they are separated in the dimension of "code". The pilots from all antennas are transmitted with preambles that use different pseudo-random noise (PN) codes. This reduces the number of time slots required for pilot signals. However, the drawback to this method is that the receiver circuitry in the mobile device must use complicated interference cancellation techniques to recover the MIMO pilot signals. This method reduces pilot signaling overhead at the cost of a more complicated pilot recovery scheme. This method also decreases the reliability of the channel estimates.

Therefore, there is a need in the art for an improved apparatus and method for performing channel estimation in a multiple-input, multiple-output (MIMO) wireless network.

SUMMARY OF THE INVENTION

In one embodiment, a base station is disclosed comprising an antenna array including M antennas for transmitting data to a plurality of subscriber stations. The channel estimation scheme is described in the context of an OFDM system. The base station generates a first pilot signal preamble by adding a first cyclic prefix to a first pilot signal sequence and generates a second pilot signal preamble by adding a second cyclic prefix to a second pilot signal sequence, wherein the second pilot signal sequence is a circularly shifted copy of the first pilot signal sequence. The first pilot signal preamble is transmitted from a first one of the M antennas and the second pilot signal preamble is transmitted from a second one of the M antennas. The first and second pilot signal preambles are transmitted concurrently.

In another embodiment, a method is disclosed for transmitting data from M antennas capable of transmitting to a plurality of subscriber stations. The disclosed method comprises the steps of: generating a first pilot signal preamble by adding a first cyclic prefix to a first pilot signal sequence; generating a second pilot signal preamble by adding a second cyclic prefix to a second pilot signal sequence, wherein the second pilot signal sequence is a circularly shifted copy of the first pilot signal sequence; transmitting the first pilot signal preamble from a first one of the M antennas; and transmitting the second pilot signal preamble from a second one of the M antennas. The first and second pilot signal preambles are transmitted concurrently.

Before undertaking the DETAILED DESCRIPTION OF THE INVENTION below, it may be advantageous to set forth definitions of certain words and phrases used throughout this patent document: the terms "include" and "comprise," as well as derivatives thereof, mean inclusion without limitation; the term "or," is inclusive, meaning and/or; the phrases "associated with" and "associated therewith," as well as derivatives thereof, may mean to include, be included within, interconnect with, contain, be contained within, connect to or with, couple to or with, be communicable with, cooperate with, interleave, juxtapose, be proximate to, be bound to or with, have, have a property of, or the like; and the term "controller" means any device, system or part thereof that controls at least one operation, such a device may be implemented in hardware, firmware or software, or some combination of at least two of the same. It should be noted that the functionality associated with any particular controller may be centralized or distributed, whether locally or remotely. Definitions for certain words and phrases are provided throughout this patent document, those of ordinary skill in the art should understand that in many, if not most instances, such definitions apply to prior, as well as future uses of such defined words and phrases.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the present disclosure and its advantages, reference is now made to the following description taken in conjunction with the accompanying drawings, in which like reference numerals represent like parts:

FIG. **1** illustrates a wireless network that implements channel estimation according to the principles of the disclosure;

ZTE/SAMSUNG/HTC 1006-0007

FIG. **2** illustrates a base station that implements channel estimation according to the principles of the disclosure;

FIG. **3** illustrates selected portions of the transmitter circuitry in a base station according to an exemplary embodiment of the present disclosure;

FIG. **4** illustrates four exemplary preambles transmitted by a base station using four antennas according to an exemplary embodiment;

FIG. **5** illustrates a cross-correlation circuit in a subscriber station; and

FIG. **6** illustrates the estimation of the channel responses $h_1(t)$, $h_2(t)$, $h_3(t)$, and $h_4(t)$ from the four (4) base station antennas to the receiving subscriber station according to one embodiment.

DETAILED DESCRIPTION OF THE INVENTION

FIGS. **1** through **6**, discussed below, and the various embodiments used to describe the principles of the present disclosure in this patent document are by way of illustration only and should not be construed in any way to limit the scope of the disclosure. Those skilled in the art will understand that the principles of the present disclosure may be implemented in any suitably arranged wireless network.

The disclosed apparatus and method for estimating wireless communication channels use pilot (or training) signals that reduce signaling overhead and require only a simple channel response estimator in the receiver of the mobile device (i.e., subscriber station, mobile station, mobile terminal, etc.). In the description that follows, the channel estimation apparatus is embodied in an orthogonal frequency division multiple access (OFDMA) wireless network using a multiple-input, multiple-output (MIMO) antenna system. However, this is by way of illustration only and should not be construed to limit the scope of the disclosure and the claims herein. Those skilled in the art will understand that the disclosed apparatus and method may be easily adapted for use in any type of wireless network that uses a multiple-input, multiple-output (MIMO) antenna system.

FIG. **1** illustrates exemplary wireless network **100**, which implements channel estimation according to the principles of the present disclosure. In the illustrated embodiment, wireless network **100** includes base station (BS) **101**, base station (BS) **102**, and base station (BS) **103**. Base station **101** communicates with base station **102** and base station **103**. Base station **101** also communicates with Internet protocol (IP) network **130**, such as the Internet, a proprietary IP network, or other data network.

Base station **102** provides wireless broadband access to network **130**, via base station **101**, to a first plurality of subscriber stations within coverage area **120** of base station **102**. The first plurality of subscriber stations includes subscriber station (SS) **111**, subscriber station (SS) **112**, subscriber station (SS) **113**, subscriber station (SS) **114**, subscriber station (SS) **115** and subscriber station (SS) **116**. In an exemplary embodiment, SS **111** may be located in a small business (SB), SS **112** may be located in an enterprise (E), SS **113** may be located in a WiFi hotspot (HS), SS **114** may be located in a first residence, SS **115** may be located in a second residence, and SS **116** may be a mobile (M) device. Base station **103** also provides wireless broadband access to network **130**, via base station **101**, to a second plurality of subscriber stations within coverage area **125** of base station **103**. The second plurality of subscriber stations includes SS **115** and SS **116**.

In order to maximize throughput, wireless network **100** estimates the communication channels between base stations **101-103** and subscriber stations **111-116**. The apparatus and method for estimating channels disclosed herein use pilot (or training) signals that reduce signaling overhead and require only a simple channel response estimator in the receivers of subscriber stations **111-116**.

FIG. **2** illustrates in greater detail exemplary base station **102**, which implements channel estimation according to one embodiment of the present disclosure. Base station **102** is illustrated by way of example only. However, it will be understood that the components illustrated and described with respect to base station **102** are also part of base stations **101** and **103**. In one embodiment, base station **102** comprises controller **225**, channel controller **235**, transceiver interface (IF) **245**, radio frequency (RF) transceiver unit **250**, and antenna array **255**. According to the principles of the present disclosure, antenna array **255** is a multiple-input, multiple output (MIMO) antenna system.

Controller **225** comprises processing circuitry and memory capable of executing an operating program that controls the overall operation of base station **102**. In an embodiment, the controller **225** may be operable to communicate with the network **130**. Under normal conditions, controller **225** directs the operation of channel controller **235**, which comprises a number of channel elements, such as exemplary channel element **240**, each of which performs bidirectional communication in the forward channel and the reverse channel. A forward channel (or downlink) refers to outbound signals from base station **102** to subscriber stations **111-116**. A reverse channel (or uplink) refers to inbound signals from subscriber stations **111-116** to base station **102**. Channel element **240** also preferably performs all baseband processing, including processing any digitized received signal to extract the information or data bits conveyed in the received signal, typically including demodulation, decoding, and error correction operations, as known to those of skill in the art. Transceiver IF **245** transfers bidirectional channel signals between channel controller **235** and RF transceiver unit **250**.

Furthermore, according to the principles of the present disclosure, antenna array **255** is a multiple-input, multiple-output (MIMO) antenna system that uses multiple antennas to transmit pilot signals and user data to subscriber stations **111-116**. Each antenna transmits its own pilot signal. Subscriber stations **111-116** use the pilot signals to estimate the channel response for each antenna in antenna array **255** using well-known channel estimation techniques.

FIG. **3** illustrates selected portions of the transmitter circuitry in base station **102** according to an exemplary embodiment of the present disclosure. Base station **102** comprises N modulation blocks **310**, including exemplary modulation blocks **310***a*-**310***c*, serial-to-parallel (S/P) converters **320**, including exemplary S/P converters **320***a*-**320***c*, inverse Fast Fourier Transform (IFFT) blocks **330**, including exemplary IFFT blocks **330***a*-**330***c*, parallel-to-serial (P/S) converters **340**, including exemplary parallel-to-serial (P/S) converters **340***a*-**340***c*, cyclic prefix insertion (CPI) blocks **350**, including exemplary CPI blocks **350***a*-**350***c*, up-conversion blocks **360**, including exemplary up-conversion blocks **360***a*-**360***c*, and antenna array **255**. Antenna array **255** comprises M antennas, including exemplary antennas **371**, **372** and **373**.

In FIG. **3**, individual transmit paths are shown for individual user data inputs, such as Data **1**, Data **2** and Data N. Each transmit path includes its own components, such as modulator block **310**, IFFT block **330**, and so forth. However, this is done for the purposes of simplicity and clarity in explaining the operation of base station **102**. In practice, many of the separate components in each transmit path may be implemented by a single functional block. For example, IFFT blocks **330***a*, **330***b* and **330***c* may all be part of a single

ZTE/SAMSUNG/HTC 1006-0008

IFFT component in base station **102**. Similarly, up-conversion blocks **360***a*, **360***b* and **360***c* may be implemented by a single up-converter in base station **102**. Additionally, some of the components in each transmit path are distributed across different ones of channel controller **235**, transceiver IF **245** and RF transceiver **250** in FIG. **2**.

In each transmit path, modulation block **310** receives an input data stream (e.g., Data **1**) and modulates the input data to produce modulated symbols according to any known modulation technique. The modulated symbols are converted to parallel format by S/P converter **320** and mapped onto a plurality of orthogonal subcarriers in the frequency domain as inputs to the IFFT block **330**. The outputs of IFFT block **330** are converted into serial data by P/S converter **340**. Cyclic prefix insertion block **350** then adds a cyclic prefix to the output of the P/S converter **340**. The output of CPI block **350** is up-converted by up-conversion block **360** for transmission via an antenna (e.g., antenna **371**) in antenna array **255**.

In each transmission time interval (TTI), base station **102** transmits a sequence of OFDM data symbols that is preceded by a pilot symbol (i.e., preamble) that trains the receiver and is used for channel estimation. CPI block **350** adds a cyclic prefix to each OFDM data symbol and to each pilot signal symbol. Thus, the first symbol of each TTI is a pilot signal preamble formed from an N-sample long pseudo-random noise (PN) code. The remaining symbols in each TTI are OFDM symbols carrying the information data.

As is well known, the result of the preamble passing through a wireless channel with a channel response, h(t), is the N-point circular convolution of p(t), the pilot signal sequence (i.e., the PN sequence/code), and h(t), the impulse response of the wireless channel. This is expressed as $p(t)\Theta h(t)$, where Θ represents the N-point circular convolution operation.

For a MIMO system, such as base station **102**, with M transmit antennas, CPI block **350** receives a pilot signal sequence, namely a PN code, p(t), and appends a cyclic prefix to the start of the pilot signal sequence. Thus, a first pilot signal preamble transmitted from a first antenna (e.g., antenna **371**) is formed directly from the original PN code. A second preamble transmitted by a second antenna (e.g., antenna **372**) is generated by circularly shifting the same PN code by L samples to produce a second pilot signal sequence and adding a second cyclic prefix. A third preamble transmitted by a third antenna (e.g., antenna **373**) is generated by circularly shifting the second pilot signal sequence by an additional L samples to produce a third pilot signal sequence and adding a third cyclic prefix.

FIG. **4** illustrates four exemplary pilot signal preambles transmitted by base station **102** using four antennas according to an exemplary embodiment. The antennas in antenna array **255** are labeled Antenna **1**, Antenna **2**, Antenna **3**, and Antenna **4** in this example. Base station **101** sends preamble **410** to Antenna **1**, preamble **420** to Antenna **2**, preamble **430** to Antenna **3**, and preamble **440** to Antenna **4**. In the exemplary embodiment, each pilot signal preamble is generated from an original pilot signal sequence that is a pseudo-random noise (PN) code that is 512 samples in length. The choice of 512 samples is by way of example only. In other embodiments, the PN code may contain more than 512 samples or less than 512 samples.

The 512 sample PN code is logically divided into eight (8) blocks, where each block contains 64 samples. The blocks are sequentially labeled [B**1** B**2** B**3** B**4** B**5** B**6** B**7** B**8**]. As is well known, a cyclic prefix for a block of N data samples is created by copying the last L samples of the block of N data samples and appending them to the front of the block of N data samples. This increases the length of the block to N+L data samples, where the first L samples and the last L samples of the block of N+L data samples are the same. Ideally, the value of L is at least as long as the channel impulse response length.

In base station **102**, CPI block **350** generates preamble **410** by copying the last L=64 samples (i.e., block B**8**) of the original pilot signal sequence, namely the 512-sample PN code [B**1** B**2** B**3** B**4** B**5** B**6** B**7** B**8**]. CPI block **350** then appends block B**8** to the start of the original pilot signal sequence to form preamble **410**. Thus, the blocks of preamble **410** are transmitted in the following order: [B**8** B**1** B**2** B**3** B**4** B**5** B**6** B**7** B**8**].

CPI block **350** generates preamble **420** in parallel with preamble **410**. CPI block **350** generates preamble **420** by circularly shifting the 512-sample PN code [B**1** B**2** B**3** B**4** B**5** B**6** B**7** B**8**] by 64 samples to the right to generate a second pilot signal sequence, namely a new 512-sample PN code: [B**8** B**1** B**2** B**3** B**4** B**5** B**6** B**7**]. Next, CPI block **350** copies the last 64 samples of the new 512-sample PN code, namely the 64 samples in block B**7**, and appends block B**7** to the start of the second pilot signal sequence. Thus, the blocks of preamble **420** are transmitted in the following order: [B**7** B**8** B**1** B**2** B**3** B**4** B**5** B**6** B**7**].

CPI block **350** generates preamble **430** in parallel with preambles **410** and **420**. CPI block **350** generates preamble **430** by circularly shifting a second time the second pilot signal sequence, namely the 512-sample PN code [B**8** B**1** B**2** B**3** B**4** B**5** B**6** B**7**], by an additional 64 samples to the right to generate a third pilot signal sequence, namely the new 512-sample PN code: [B**7** B**8** B**1** B**2** B**3** B**4** B**5** B**6**]. Next, CPI block **350** copies the last 64 samples of the new 512-sample PN code, namely the 64 samples in block B**6**, and appends block B**6** to the start of the third pilot signal sequence. Thus, the blocks of preamble **430** are transmitted in the following order: [B**6** B**7** B**8** B**1** B**2** B**3** B**4** B**5** B**6**].

CPI block **350** generates preamble **440** in parallel with preambles **410**, **420** and **430**. CPI block **350** generates preamble **440** by circularly shifting a third time the second pilot signal sequence, namely the 512-sample PN code [B**7** B**8** B**1** B**2** B**3** B**4** B**5** B**6**], by an additional 64 samples to the right to generate a fourth pilot signal sequence, namely the new 512-sample PN code: [B**6** B**7** B**8** B**1** B**2** B**3** B**4** B**5**]. Next, CPI block **350** copies the last 64 samples of the new 512 sample PN code, namely the 64 samples in block B**5**, and appends block B**5** to the start of the fourth pilot signal sequence. Thus, the blocks of preamble **440** are transmitted in the following order: [B**5** B**6** B**7** B**8** B**1** B**2** B**3** B**4** B**5**].

It is noted that the circular shift of 64 samples for each one of preambles **420**, **430** and **440** is by way of example only. In alternate embodiments, a circular shift of more than 64 samples or less than 64 samples may be used.

After transmission from Antennas **1**, **2**, **3** and **4**, preambles **410**, **420**, **430** and **440** are received at a subscriber station at the same time. At the receiving subscriber station, it is assumed that the channel response for Antenna **1** is $h_1(t)$, the channel response for Antenna **2** is $h_2(t)$, the channel response for Antenna **3** is $h_3(t)$, and the channel response for Antenna **4** is $h_4(t)$. Thus, the baseband signal, r(t), in the receiving subscriber station may be represented as:

$$r(t)=p(t)\Theta h_1(t)+p[t-64]_N\Theta h_2(t)+p[t-128]_N\Theta h_3(t)+p[t-192]_N\Theta h_4(t)+n(t)$$

In the above equation, $p[t-1]_N$ is the L-sample circularly shifted version of the N-sample long sequence p(t) and n(t) is the white Gaussian noise. In this example, L=64 and N=512.

In the absence of noise, the channel responses $h_1(t)$, $h_2(t)$, $h_3(t)$, and $h_4(t)$ may be ideally identified by the circular

ZTE/SAMSUNG/HTC 1006-0009

(cross) correlation of r(t) and p(t). FIG. **5** illustrates cross-correlation circuit **500** in a subscriber station. Cross-correlation circuit **500** receives the baseband signal, r(t), and the original 512 sample PN code, p(t), of the pilot signal and generates the channel responses $h_1(t)$, $h_2(t)$, $h_3(t)$, and $h_4(t)$.

FIG. **6** depicts timing diagram **600**, which illustrates the estimation of the channel responses $h_1(t)$, $h_2(t)$, $h_3(t)$, and $h_4(t)$ in the receiving subscriber station according to one embodiment. Because of the circular shifts of preambles **420**, **430** and **440** with respect to preamble **410**, the receiver in the subscriber station sequentially detects the channel responses $h_1(t)$, $h_2(t)$, $h_3(t)$, and $h_4(t)$. Thus, it is not necessary to include complex cancellation circuitry in the receiver to cancel, for example, the channel response $h_1(t)$ from the channel response $h_2(t)$.

The disclosed apparatus and method employ the circular shift orthogonal property of a pre-designed pseudo-random (PN) code. Each antenna transmits a circularly shifted version of the PN code, and at the receiver, one cross-correlation operation enables the identification of all channel responses, as long as the product (L×M) of the channel impulse response length, L, and the number of antennas, M, does not exceed the length N of the PN code.

Although the present disclosure has been described with an exemplary embodiment, various changes and modifications may be suggested to one skilled in the art. It is intended that the present disclosure encompass such changes and modifications as fall within the scope of the appended claims.

What is claimed is:

1. A base station configured to communicate with a plurality of subscriber stations of a wireless network, the base station comprising:

an antenna array comprising a plurality of antennas configured to transmit data to the plurality of subscriber stations; and

a cyclic prefix insertion block configured to:

generate a first pilot signal preamble by adding a first cyclic prefix to a first pilot signal sequence;

generate a second pilot signal preamble by adding a second cyclic prefix to a second pilot signal sequence; and

transmit the first and second pilot signal preambles through the plurality of antennas,

wherein the second pilot signal sequence is a circularly shifted copy of the first pilot signal sequence,

wherein the first cyclic prefix comprises the last one or more samples of the first pilot signal sequence, and

wherein a product of the length of the first and second cyclic prefix and the number of antennas does not exceed a length of the first and second pilot signal sequence, respectively.

2. The base station as set forth in claim **1**, wherein the cyclic prefix insertion block is configured to transmit the first pilot signal preamble from a first one of the plurality of antennas and the second pilot signal preamble from a second one of the plurality of antennas, wherein the first and second pilot signal preambles are transmitted concurrently.

3. The base station as set forth in claim **2**, wherein the first pilot signal sequence comprises a pseudo-random noise code.

4. The base station as set forth in claim **3**, wherein the cyclic prefix insertion block is configured to generate the second pilot signal sequence by circularly shifting the first pilot signal sequence by one or more samples to the right.

5. The base station as set forth in claim **4**, wherein the second cyclic prefix comprises the last one or more samples of the second pilot signal sequence.

6. The base station as set forth in claim **2**, wherein the cyclic prefix insertion block is configured to generate a third pilot signal preamble by adding a third cyclic prefix to a third pilot signal sequence, wherein the third pilot signal sequence comprises a circularly shifted copy of the second pilot signal sequence.

7. The base station as set forth in claim **6**, wherein the cyclic prefix insertion block is configured to transmit the third pilot signal preamble from a third one of the plurality of antennas, wherein the first, second and third pilot signal preambles are transmitted concurrently.

8. A wireless network comprising a plurality of base stations configured to communicate with a plurality of subscriber stations, each one of the plurality of base stations comprising:

an antenna array comprising a plurality of antennas configured to transmit data to the plurality of subscriber stations; and

a cyclic prefix insertion block configured to:

generate a first pilot signal preamble by adding a first cyclic prefix to a first pilot signal sequence;

generate a second pilot signal preamble by adding a second cyclic prefix to a second pilot signal sequence; and

transmit the first and second pilot signal preambles through the plurality of antennas,

wherein the second pilot signal sequence is a circularly shifted copy of the first pilot signal sequence, wherein the second cyclic prefix comprises the last one or more samples of the second pilot signal sequence,

wherein a product of the length of the first and second cyclic prefix and the number of antennas does not exceed a length of the first and second pilot signal sequence, respectively.

9. The wireless network as set forth in claim **8**, wherein the cyclic prefix insertion block is configured to transmit the first pilot signal preamble from a first one of the plurality of antennas and the second pilot signal preamble from a second one of the plurality of antennas, wherein the first and second pilot signal preambles are transmitted concurrently.

10. The wireless network as set forth in claim **9**, wherein the first pilot signal sequence comprises a pseudo-random noise code.

11. The wireless network as set forth in claim **10**, wherein the first cyclic prefix comprises the last one or more samples of the first pilot signal sequence.

12. The wireless network as set forth in claim **11**, wherein the cyclic prefix insertion block is configured to generate the second pilot signal sequence by circularly shifting the first pilot signal sequence by one or more samples to the right.

13. The wireless network as set forth in claim **12**, wherein the cyclic prefix insertion block is configured to generate a third pilot signal preamble by adding a third cyclic prefix to a third pilot signal sequence, wherein the third pilot signal sequence comprises a circularly shifted copy of the second pilot signal sequence.

14. The wireless network as set forth in claim **13**, wherein the cyclic prefix insertion block is configured to transmit the third pilot signal preamble from a third one of the plurality of antennas, wherein the first, second and third pilot signal preambles are transmitted concurrently.

15. A method for transmitting from an antenna array comprising a plurality of antennas that transmit data to a plurality of subscriber stations, the method comprising:

generating a first pilot signal preamble by adding a first cyclic prefix to a first pilot signal sequence;

ZTE/SAMSUNG/HTC 1006-0010

generating a second pilot signal preamble by adding a second cyclic prefix to a second pilot signal sequence, wherein the second pilot signal sequence is a circularly shifted copy of the first pilot signal sequence;

transmitting the first pilot signal preamble from a first one of the plurality of antennas; and

transmitting the second pilot signal preamble from a second one of the plurality of antennas, wherein the first and second pilot signal preambles are transmitted concurrently,

wherein the first cyclic prefix comprises the last one or more samples of the first pilot signal sequence, and

wherein a product of the length of the first and second cyclic prefix and the number of antennas does not exceed a length of the first and second pilot signal sequence, respectively.

16. The method as set forth in claim **15**, wherein the first pilot signal sequence comprises a pseudo-random noise code.

17. The method as set forth in claim **16**, wherein generating the second pilot signal sequence comprises generating the second pilot signal sequence by circularly shifting the first pilot signal sequence by one or more samples to the right.

18. The method as set forth in claim **17**, wherein the second cyclic prefix comprises the last one or more samples of the second pilot signal sequence.

19. A base station comprising an antenna array including a plurality of antennas configured to transmit data to a plurality of subscriber stations, wherein the base station is configured to:

generate a first pilot signal preamble by adding a first cyclic prefix to a first pilot signal sequence ; and

generate a second pilot signal preamble by adding a second cyclic prefix to a second pilot signal sequence,

wherein the second pilot signal sequence comprises a circularly shifted copy of the first pilot signal sequence,

wherein the first cyclic prefix comprises the last one or more samples of the first pilot signal sequence, and

wherein a product of the length of the first and second cyclic prefix and the number of antennas does not exceed a length of the first and second pilot signal sequence, respectively.

20. The base station as set forth in claim **19**, wherein the base station is configured to transmit the first pilot signal preamble from a first one of the plurality of antennas and the second pilot signal preamble from a second one of the plurality of antennas, wherein the first and second pilot signal preambles are transmitted concurrently.

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