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(54) **NETWORK ASSISTED INTERFERENCE MITIGATION**

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H04L 5/00	(2006.01)

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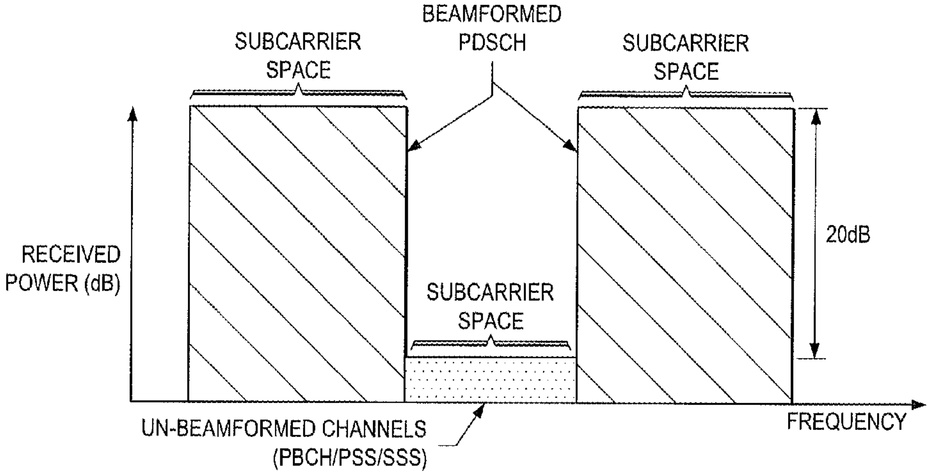
USPC **370/329**

(57) **ABSTRACT**

A method for network assisted interference mitigation includes identifying at least one pair of adjacent resource blocks within a same subframe. The at least one pair includes a low power resource block (RB) and a high power RB. The low power RB has a substantially lower beamforming gain compared to the high beamforming gain of the high power RB such that a ratio (R) comparing receive powers of the high power RB and the low power RB to each other is greater than a threshold ratio (μ). The method includes reducing a transmit power of the high power RE to a reduced transmit power level at which the ratio R is less than or equal to the threshold ratio μ (R≤μ).



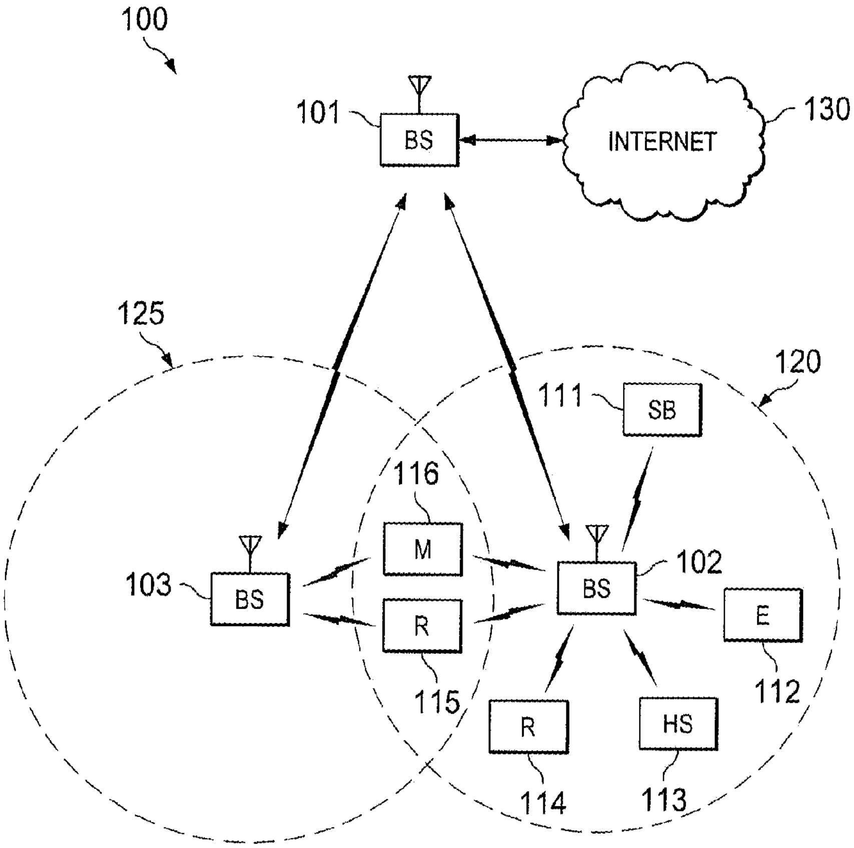

100
101
BS
INTERNET
130
125
120
111
SB
116
M
102
BS
103
BS
R
E
112
115
R
HS
114
113

FIG. 1

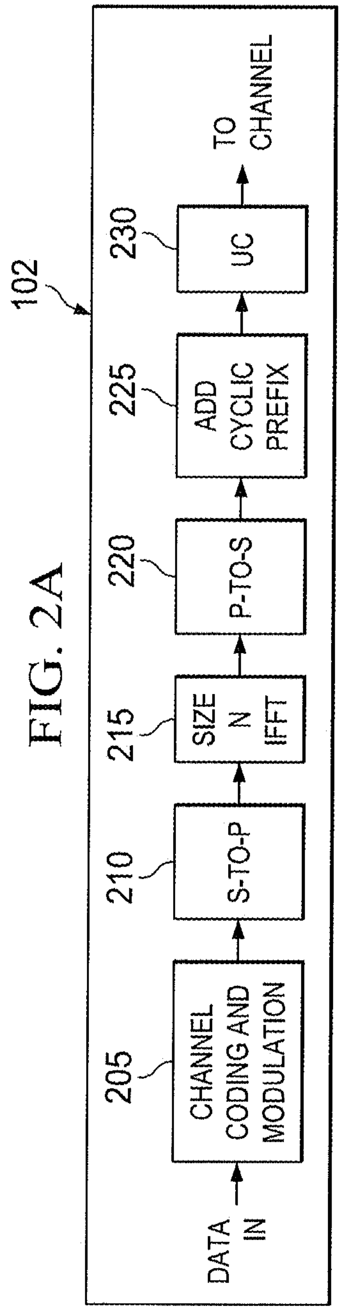

102
DATA IN
205
CHANNEL CODING AND MODULATION
210
S-TO-P
215
SIZE N IFFT
220
P-TO-S
225
ADD CYCLIC PREFIX
230
UC
TO CHANNEL

FIG. 2A

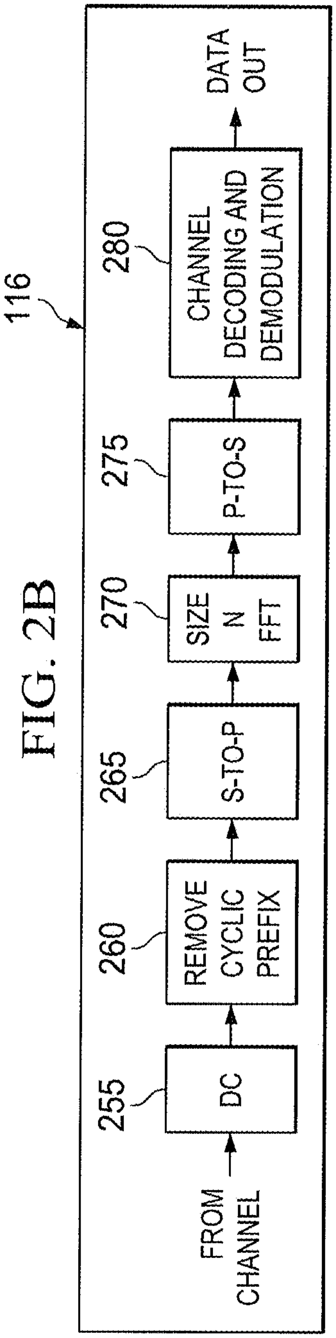

116
FROM CHANNEL
255
DC
260
REMOVE CYCLIC PREFIX
265
S-TO-P
270
SIZE N FFT
275
P-TO-S
280
CHANNEL DECODING AND DEMODULATION
DATA OUT

FIG. 2B

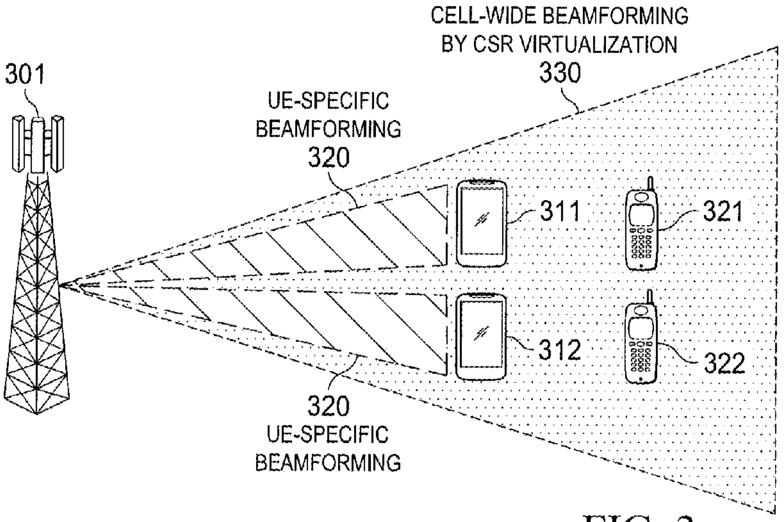

CELL-WIDE BEAMFORMING
BY CSR VIRTUALIZATION
330
301
UE-SPECIFIC
BEAMFORMING
320
311
321
312
322
320
UE-SPECIFIC
BEAMFORMING

FIG. 3

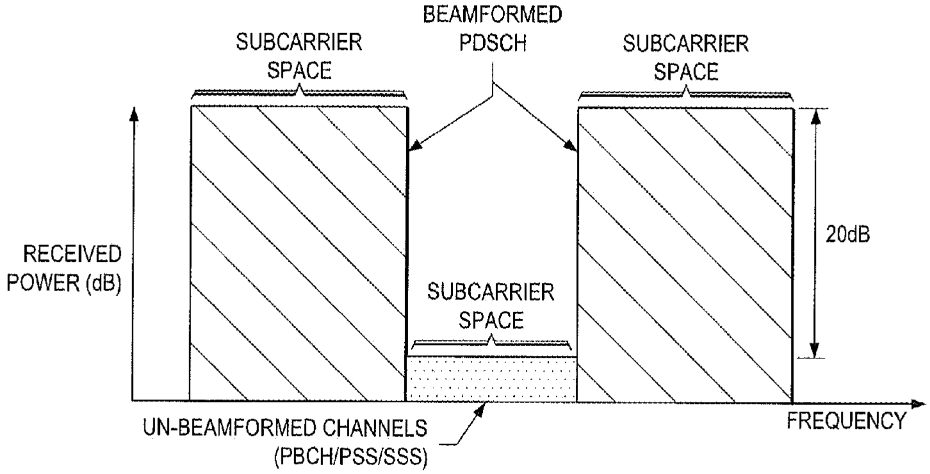

BEAMFORMED
PDSCH
SUBCARRIER
SPACE
SUBCARRIER
SPACE
RECEIVED
POWER (dB)
SUBCARRIER
SPACE
20dB
UN-BEAMFORMED CHANNELS
(PBCH/PSS/SSS)
FREQUENCY

FIG. 4

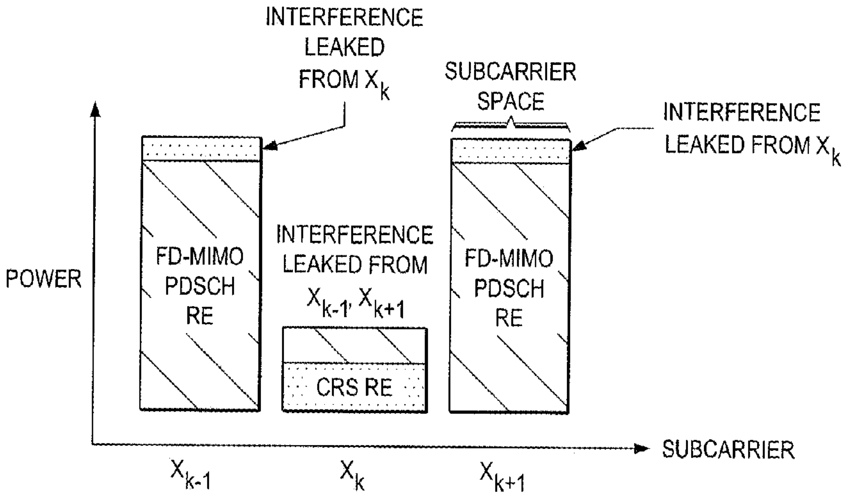

INTERFERENCE LEAKED FROM X_k
SUBCARRIER SPACE
INTERFERENCE LEAKED FROM X_k
POWER
FD-MIMO PDSCH RE
INTERFERENCE LEAKED FROM X_{k-1}, X_{k+1}
CRS RE
FD-MIMO PDSCH RE
SUBCARRIER
X_{k-1}
X_k
X_{k+1}

FIG. 5

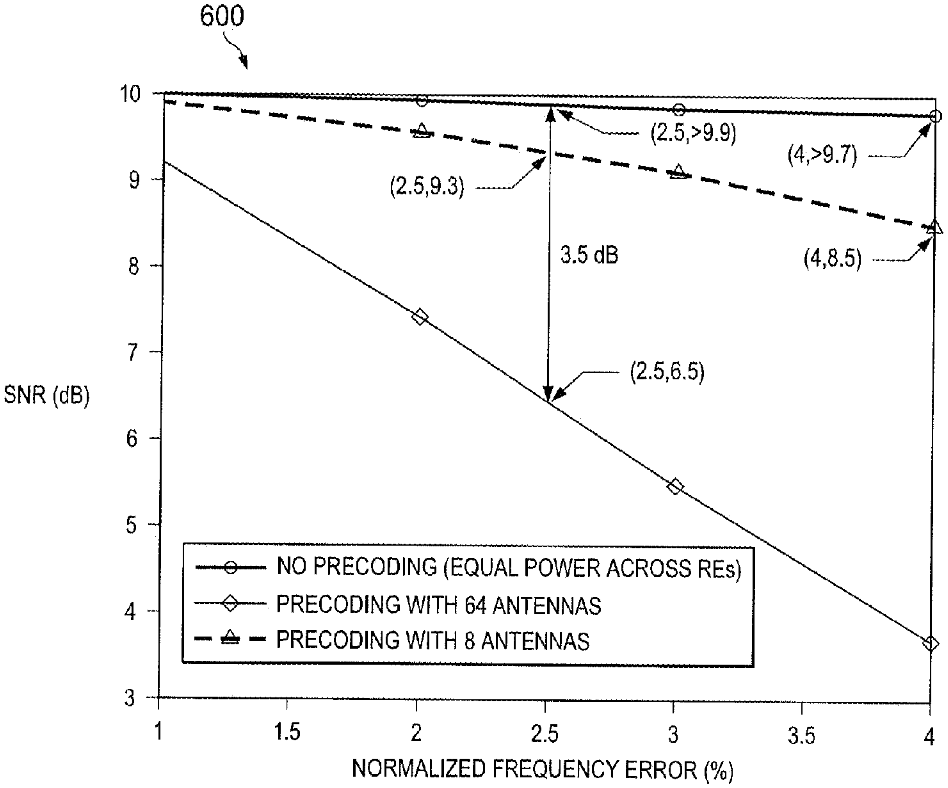

600
SNR (dB)
10
9
8
7
6
5
4
3
1
1.5
2
2.5
3
3.5
4
NORMALIZED FREQUENCY ERROR (%)
(2.5,>9.9)
(4,>9.7)
(2.5,9.3)
(4,8.5)
3.5 dB
(2.5,6.5)
NO PRECODING (EQUAL POWER ACROSS REs)
PRECODING WITH 64 ANTENNAS
PRECODING WITH 8 ANTENNAS

FIG. 6

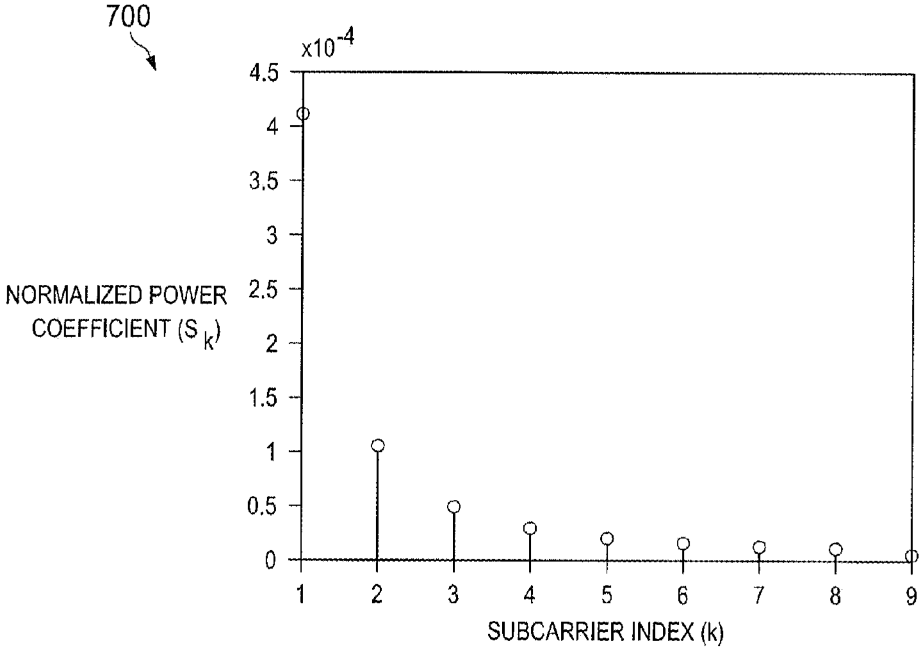


FIG. 7

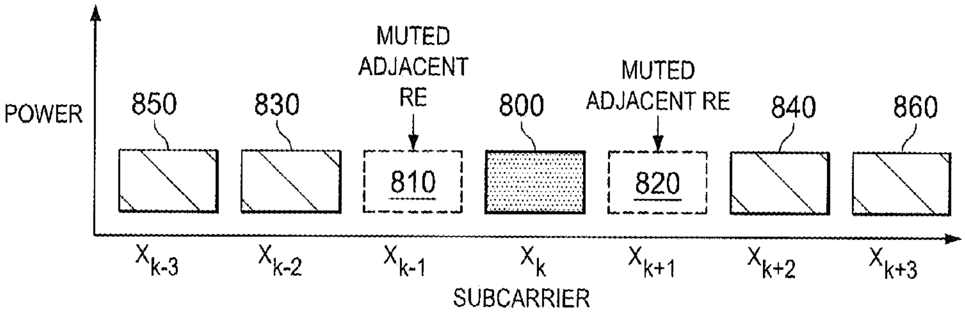


FIG. 8A

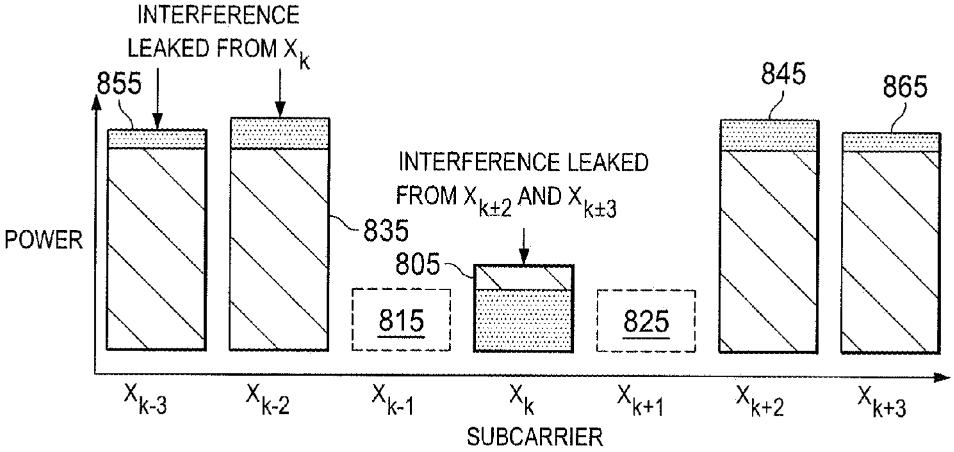


FIG. 8B

FIG. 9A

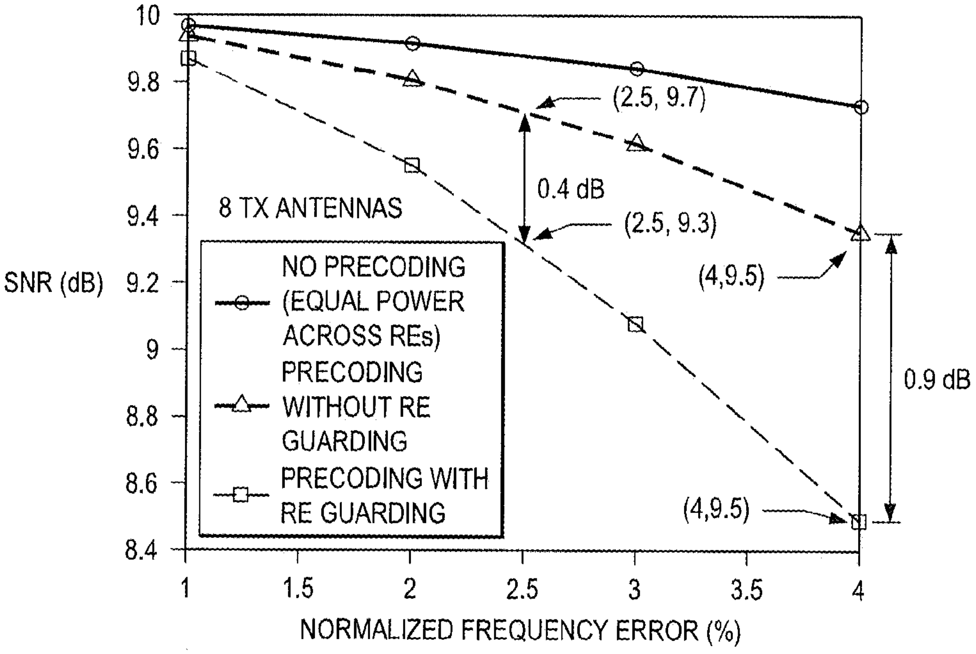

10
9.8
9.6
9.4
9.2
9
8.8
8.6
8.4
SNR (dB)
1
1.5
2
2.5
3
3.5
4
NORMALIZED FREQUENCY ERROR (%)
8 TX ANTENNAS
(2.5, 9.7)
0.4 dB
(2.5, 9.3)
(4,9.5)
0.9 dB
(4,9.5)
NO PRECODING (EQUAL POWER ACROSS REs)
PRECODING WITHOUT RE GUARDING
PRECODING WITH RE GUARDING

FIG. 9B

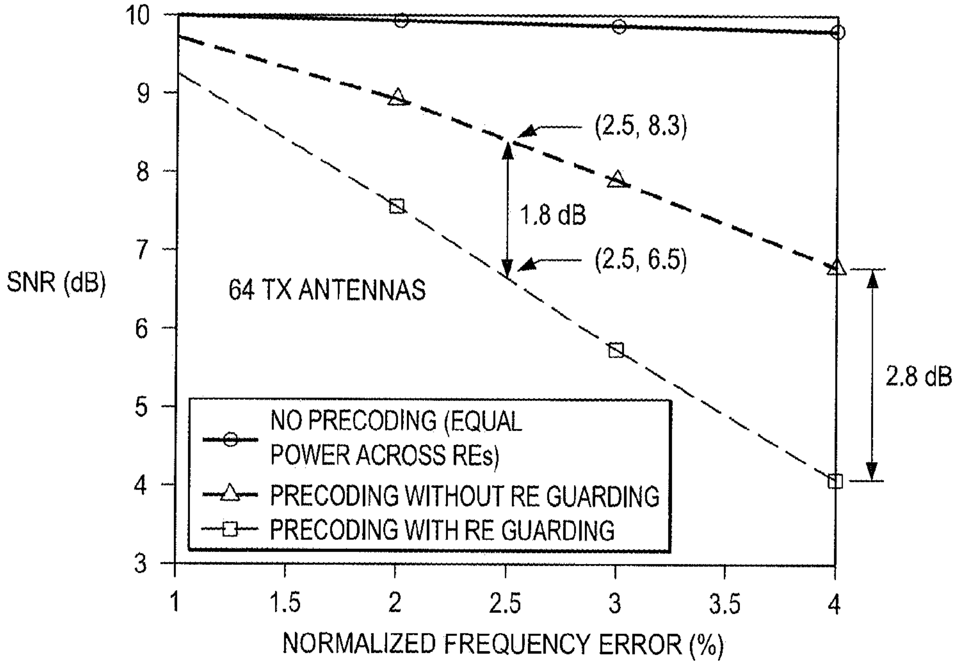

10
9
8
7
6
5
4
3
SNR (dB)
1
1.5
2
2.5
3
3.5
4
NORMALIZED FREQUENCY ERROR (%)
64 TX ANTENNAS
(2.5, 8.3)
1.8 dB
(2.5, 6.5)
2.8 dB
NO PRECODING (EQUAL POWER ACROSS REs)
PRECODING WITHOUT RE GUARDING
PRECODING WITH RE GUARDING

FIG. 10A

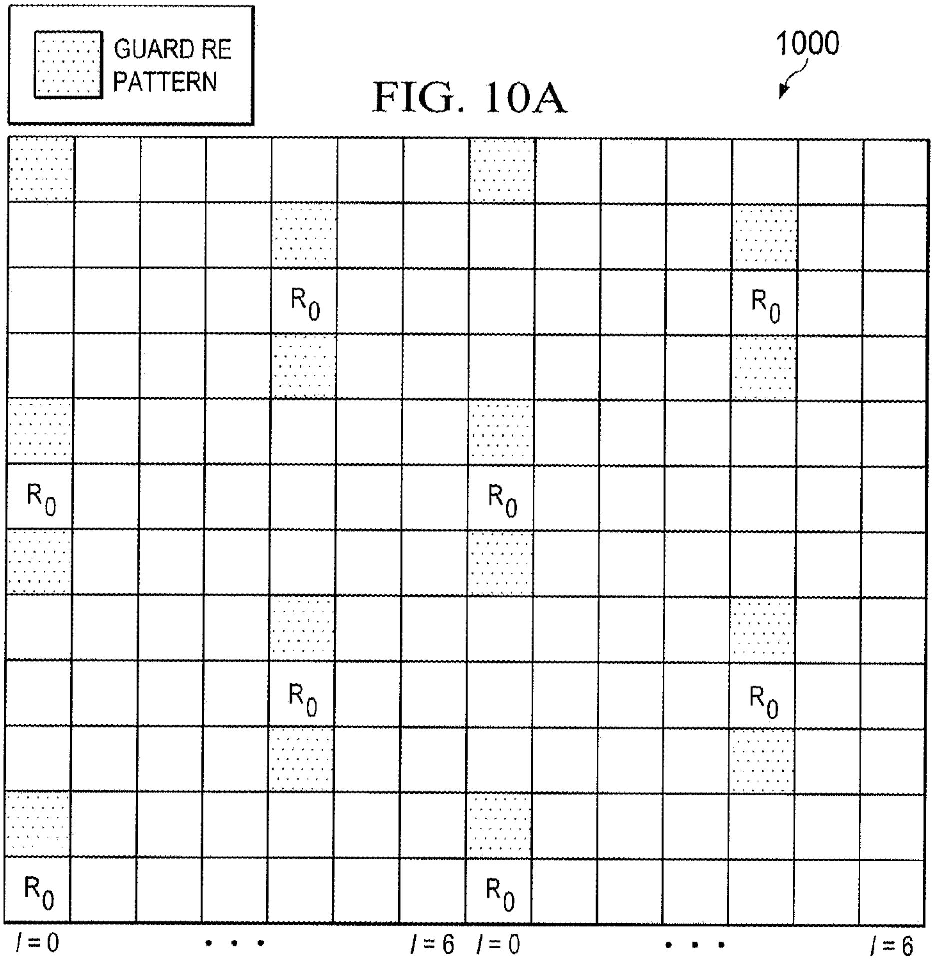
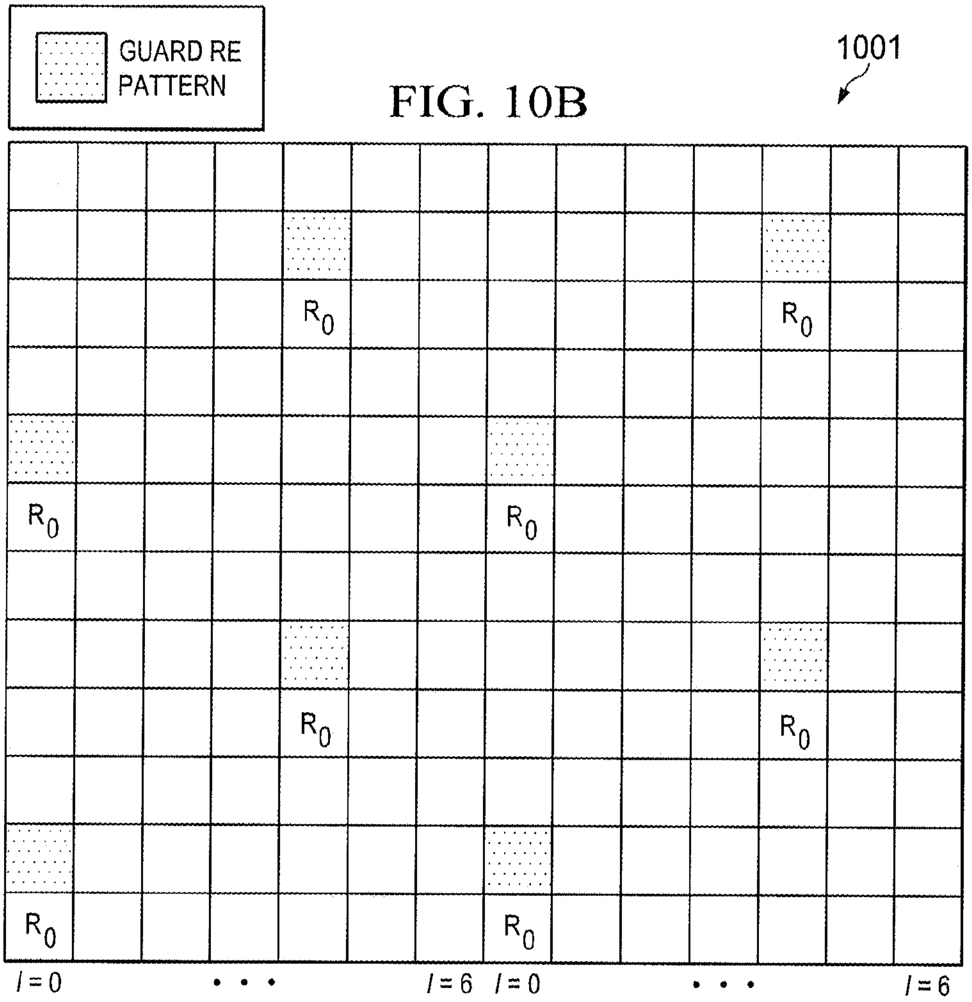


FIG. 10B



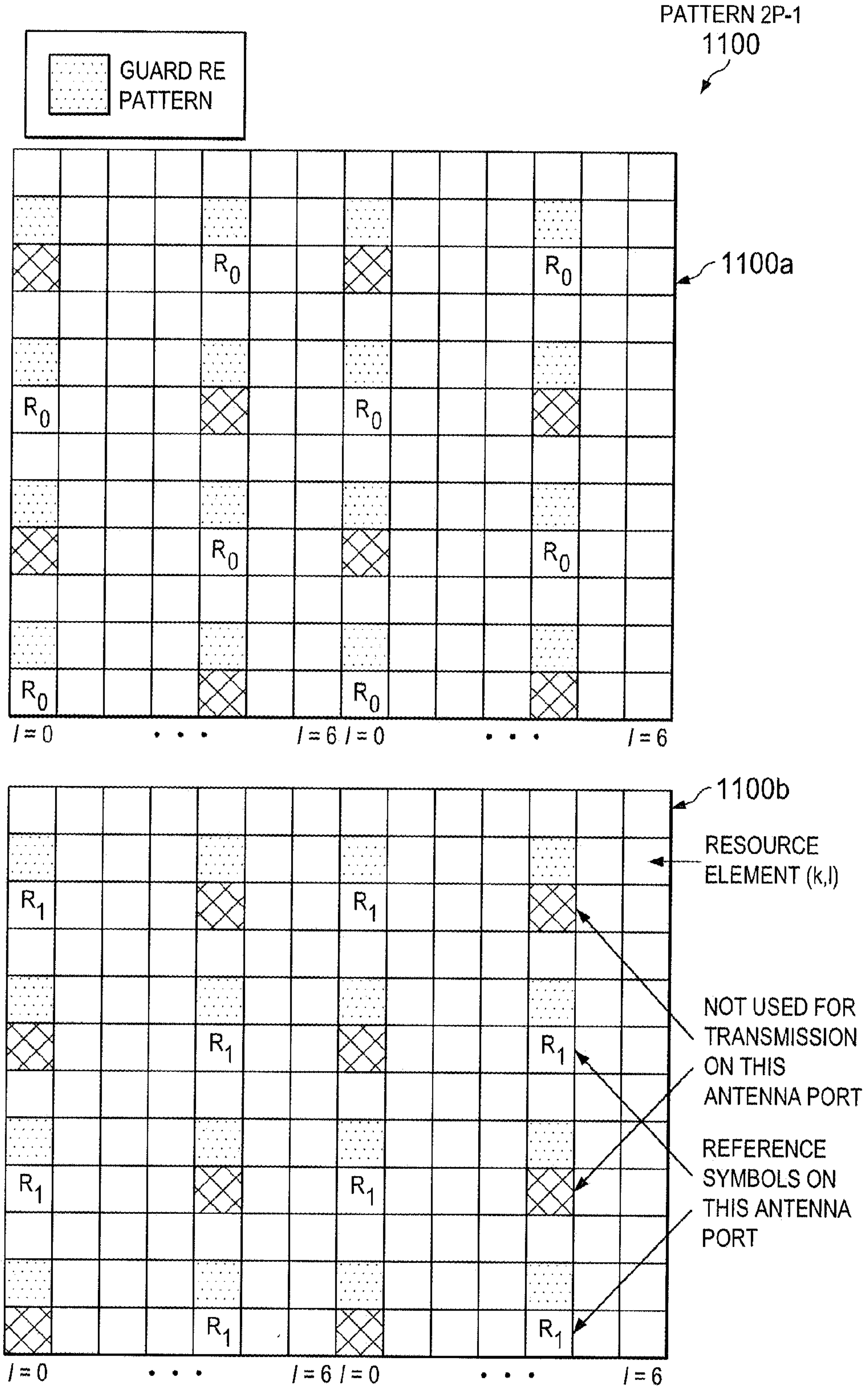

GUARD RE PATTERN
PATTERN 2P-1
1100
1100a
R_0
$l = 0$
• • •
$l = 6$
1100b
R_1
RESOURCE ELEMENT (k,l)
NOT USED FOR TRANSMISSION ON THIS ANTENNA PORT
REFERENCE SYMBOLS ON THIS ANTENNA PORT

FIG. 11A

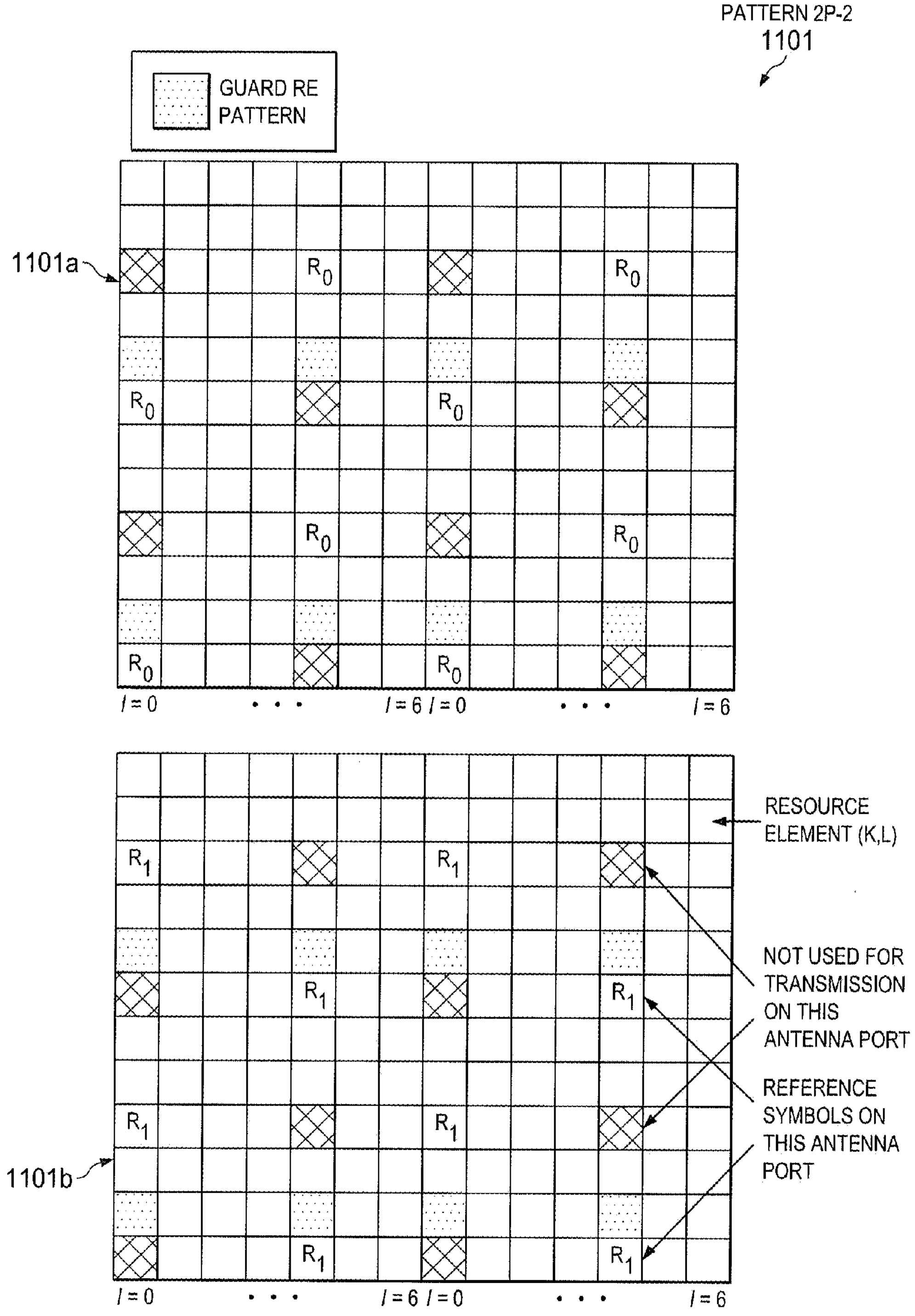

PATTERN 2P-2
1101
GUARD RE PATTERN
1101a
R0
1101b
R1
l = 0
l = 6
RESOURCE ELEMENT (K,L)
NOT USED FOR TRANSMISSION ON THIS ANTENNA PORT
REFERENCE SYMBOLS ON THIS ANTENNA PORT

FIG. 11B

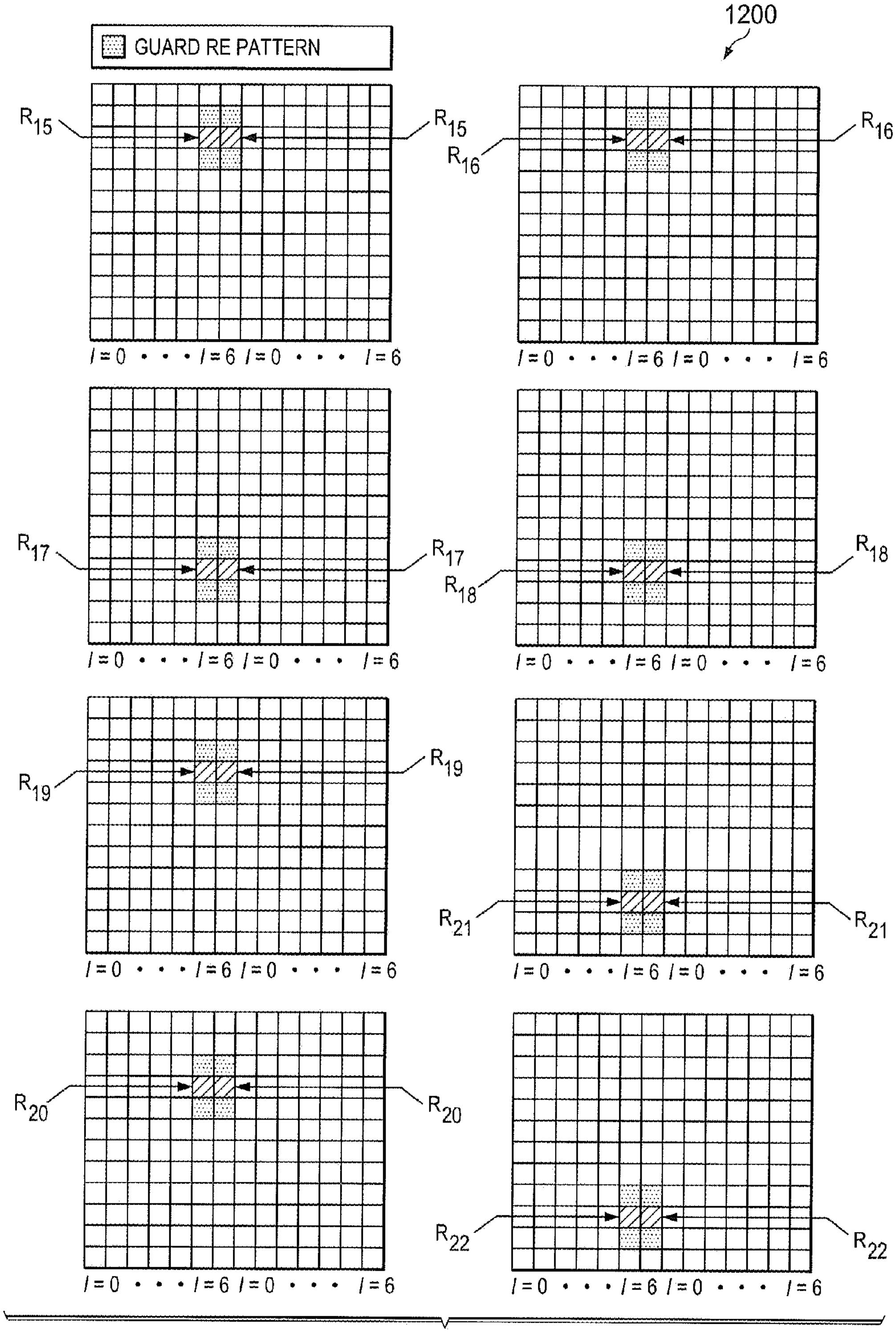

1200
▨ GUARD RE PATTERN
R15
R15
R16
R16
R17
R17
R18
R18
R19
R19
R21
R21
R20
R20
R22
R22
l = 0 • • • l = 6 l = 0 • • • l = 6

FIG. 12A

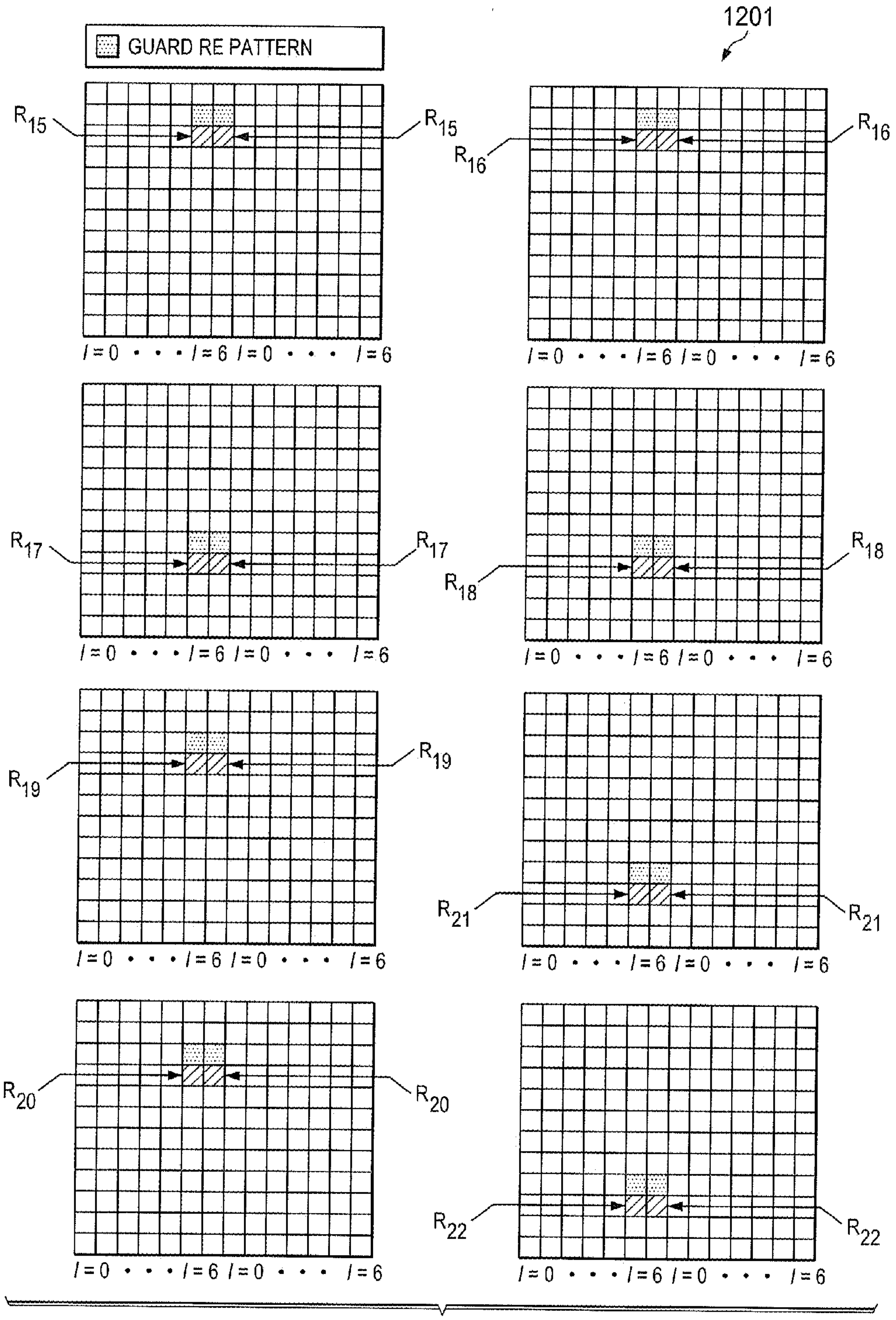

GUARD RE PATTERN
1201
R_{15}
R_{15}
R_{16}
R_{16}
R_{17}
R_{17}
R_{18}
R_{18}
R_{19}
R_{19}
R_{21}
R_{21}
R_{20}
R_{20}
R_{22}
R_{22}
$l = 0$ • • • $l = 6$ $l = 0$ • • • $l = 6$

FIG. 12B

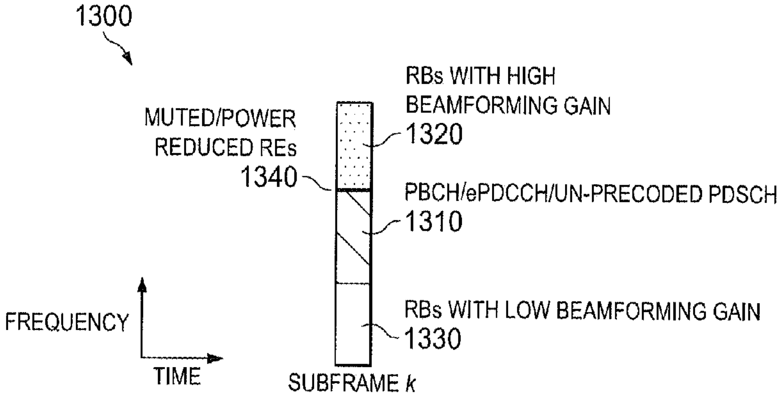


FIG. 13

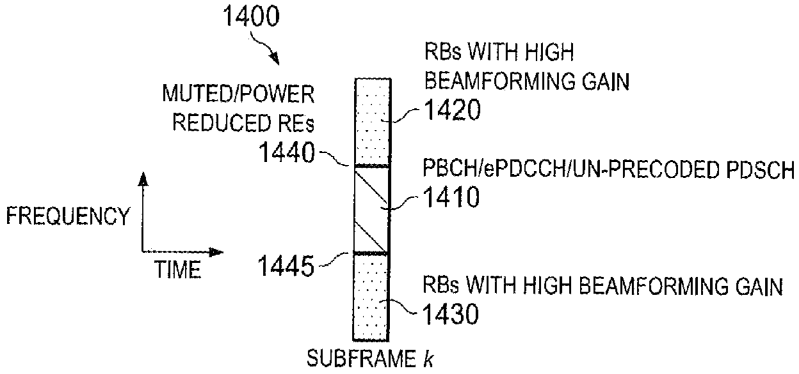


FIG. 14

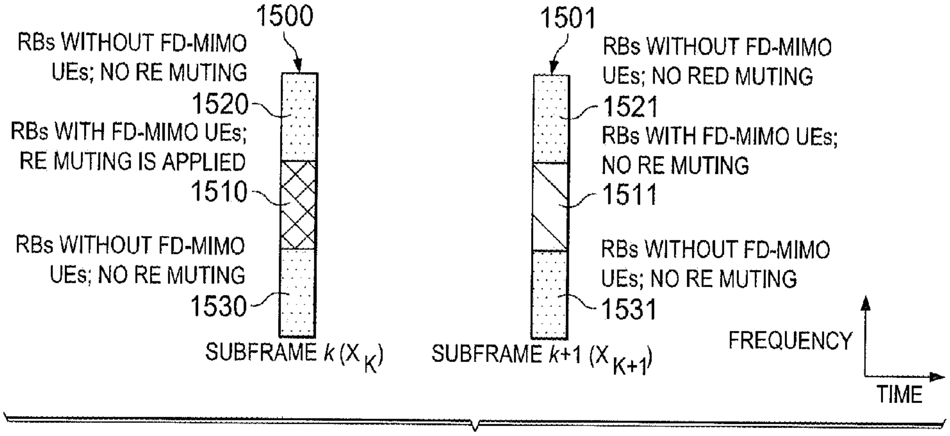
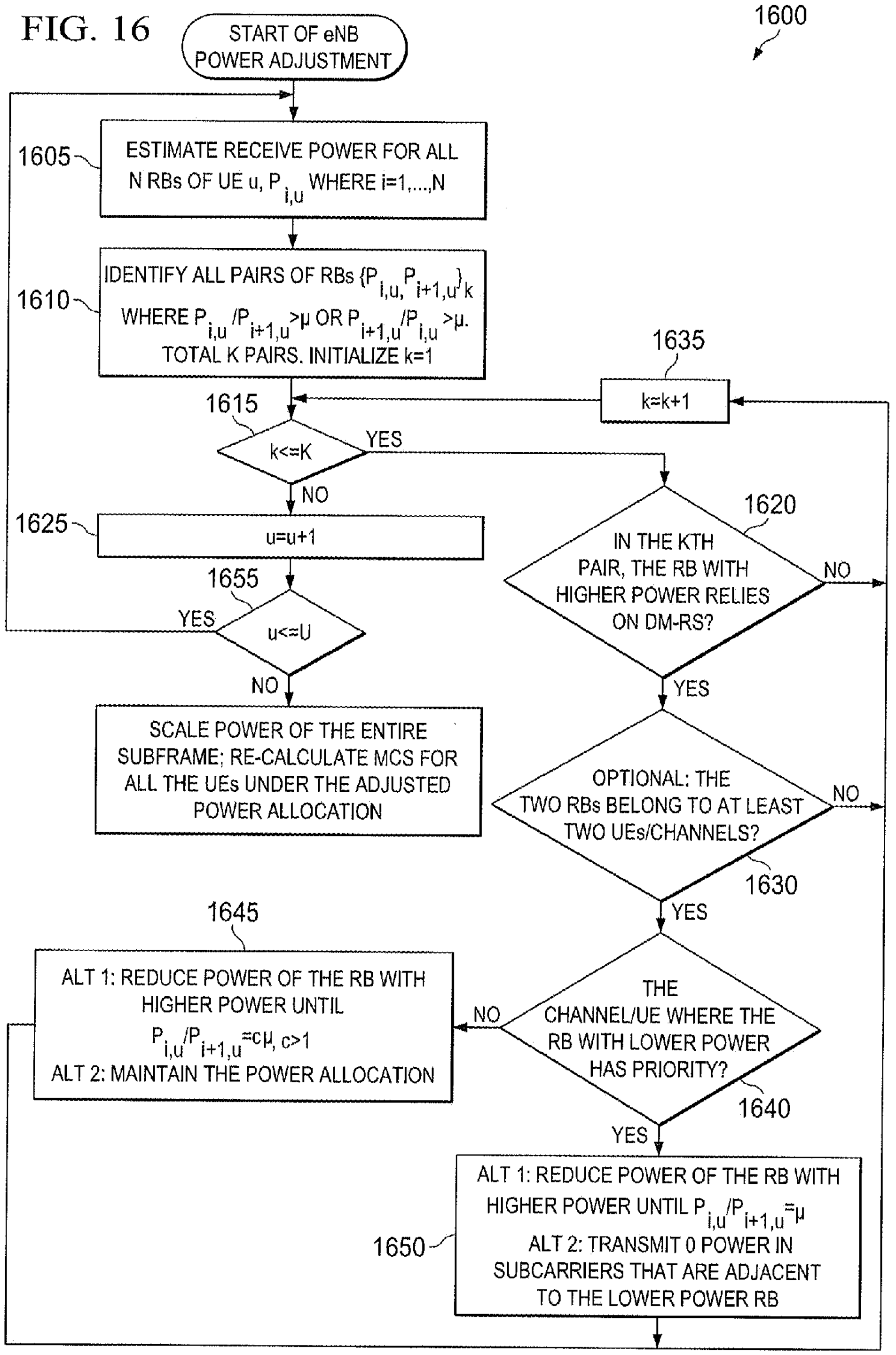


FIG. 15

FIG. 16


1600
START OF eNB POWER ADJUSTMENT
1605
ESTIMATE RECEIVE POWER FOR ALL N RBs OF UE u, $P_{i,u}$ WHERE i=1,...,N
1610
IDENTIFY ALL PAIRS OF RBs $\{P_{i,u}, P_{i+1,u}\}_k$ WHERE $P_{i,u}/P_{i+1,u}>\mu$ OR $P_{i+1,u}/P_{i,u}>\mu$. TOTAL K PAIRS. INITIALIZE k=1
1615
k<=K
YES
NO
1635
k=k+1
1620
IN THE KTH PAIR, THE RB WITH HIGHER POWER RELIES ON DM-RS?
NO
YES
1625
u=u+1
1655
u<=U
YES
NO
SCALE POWER OF THE ENTIRE SUBFRAME; RE-CALCULATE MCS FOR ALL THE UEs UNDER THE ADJUSTED POWER ALLOCATION
1630
OPTIONAL: THE TWO RBs BELONG TO AT LEAST TWO UEs/CHANNELS?
NO
YES
1645
ALT 1: REDUCE POWER OF THE RB WITH HIGHER POWER UNTIL $P_{i,u}/P_{i+1,u}=c\mu$, c>1
ALT 2: MAINTAIN THE POWER ALLOCATION
NO
1640
THE CHANNEL/UE WHERE THE RB WITH LOWER POWER HAS PRIORITY?
YES
1650
ALT 1: REDUCE POWER OF THE RB WITH HIGHER POWER UNTIL $P_{i,u}/P_{i+1,u}=\mu$
ALT 2: TRANSMIT 0 POWER IN SUBCARRIERS THAT ARE ADJACENT TO THE LOWER POWER RB

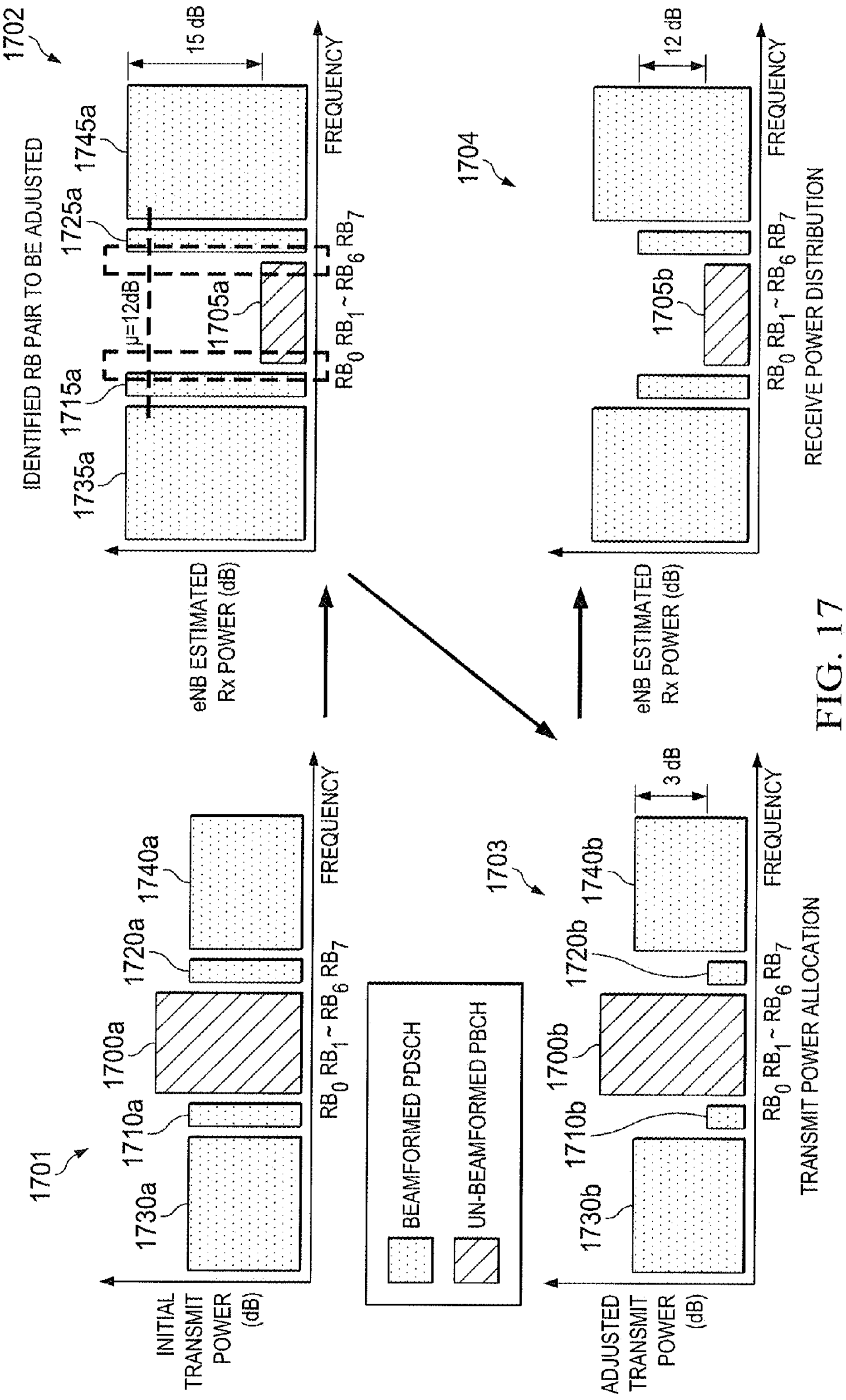

1701
INITIAL TRANSMIT POWER (dB)
1730a
1710a
1700a
1720a
1740a
RB_0 RB_1 ~ RB_6 RB_7
FREQUENCY
▨ BEAMFORMED PDSCH
▨ UN-BEAMFORMED PBCH
1702
IDENTIFIED RB PAIR TO BE ADJUSTED
1735a
1715a
1705a
1725a
1745a
μ=12dB
15 dB
eNB ESTIMATED Rx POWER (dB)
RB_0 RB_1 ~ RB_6 RB_7
FREQUENCY
1703
ADJUSTED TRANSMIT POWER (dB)
1730b
1710b
1700b
1720b
1740b
3 dB
RB_0 RB_1 ~ RB_6 RB_7
FREQUENCY
TRANSMIT POWER ALLOCATION
1704
eNB ESTIMATED Rx POWER (dB)
1705b
12 dB
RB_0 RB_1 ~ RB_6 RB_7
FREQUENCY
RECEIVE POWER DISTRIBUTION

FIG. 17

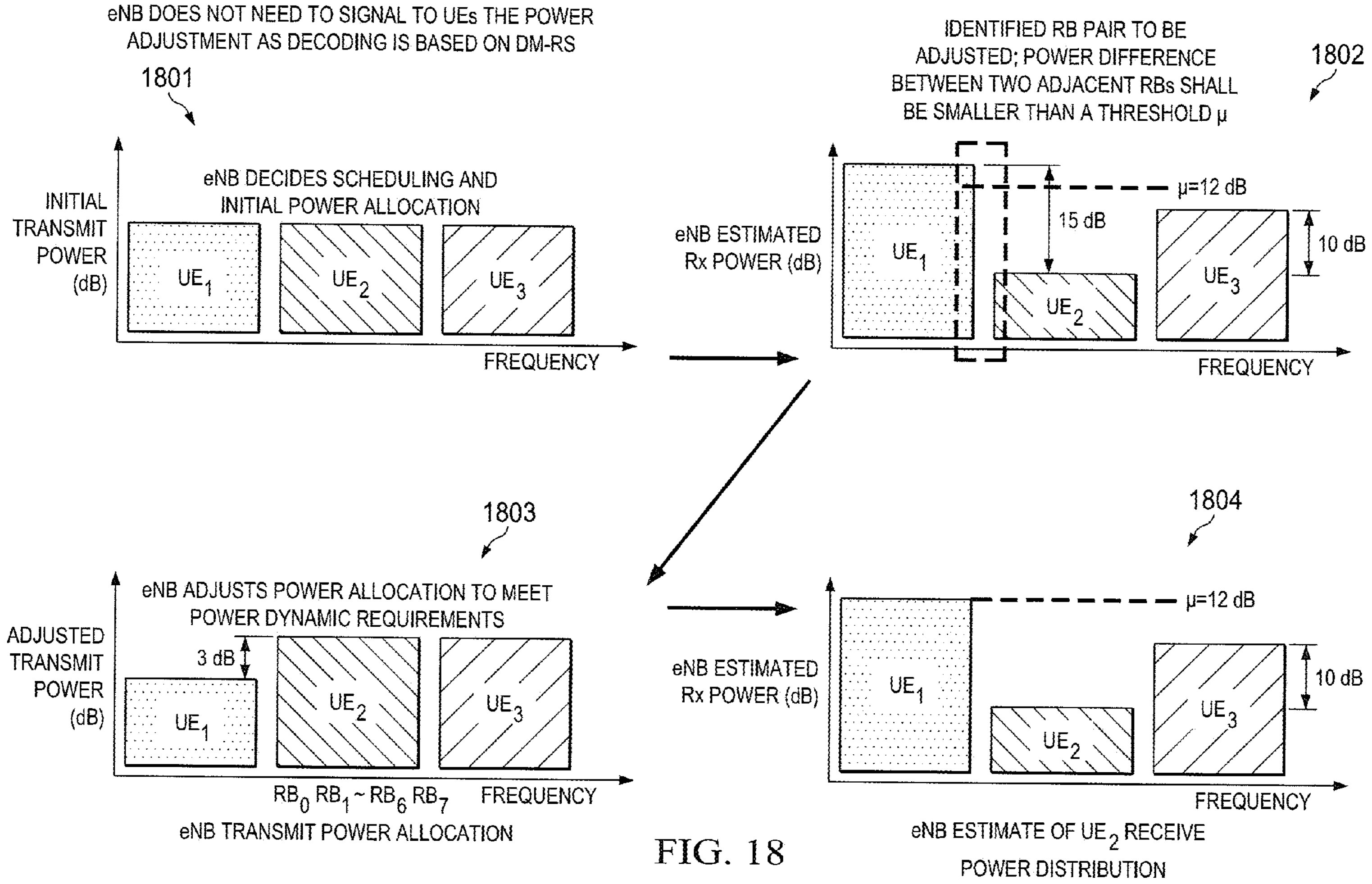

eNB DOES NOT NEED TO SIGNAL TO UEs THE POWER ADJUSTMENT AS DECODING IS BASED ON DM-RS
1801
INITIAL TRANSMIT POWER (dB)
eNB DECIDES SCHEDULING AND INITIAL POWER ALLOCATION
UE_1
UE_2
UE_3
FREQUENCY
IDENTIFIED RB PAIR TO BE ADJUSTED; POWER DIFFERENCE BETWEEN TWO ADJACENT RBs SHALL BE SMALLER THAN A THRESHOLD μ
1802
eNB ESTIMATED Rx POWER (dB)
μ=12 dB
15 dB
10 dB
UE_1
UE_2
UE_3
FREQUENCY
1803
eNB ADJUSTS POWER ALLOCATION TO MEET POWER DYNAMIC REQUIREMENTS
ADJUSTED TRANSMIT POWER (dB)
3 dB
UE_1
UE_2
UE_3
RB_0 RB_1 ~ RB_6 RB_7
FREQUENCY
eNB TRANSMIT POWER ALLOCATION
1804
eNB ESTIMATED Rx POWER (dB)
μ=12 dB
10 dB
UE_1
UE_2
UE_3
FREQUENCY
eNB ESTIMATE OF UE_2 RECEIVE POWER DISTRIBUTION

FIG. 18

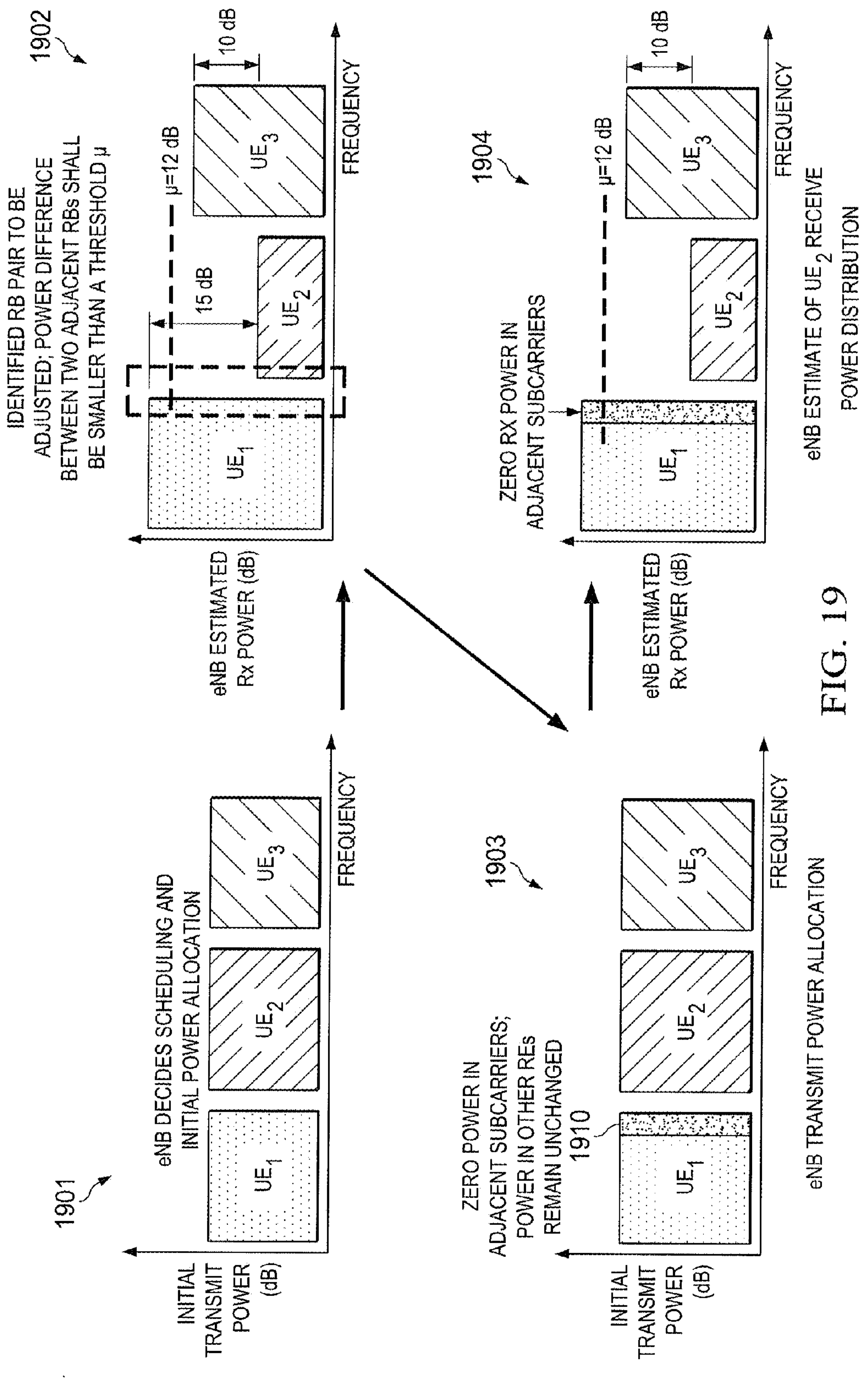

1901
eNB DECIDES SCHEDULING AND INITIAL POWER ALLOCATION
INITIAL TRANSMIT POWER (dB)
UE_1
UE_2
UE_3
FREQUENCY
1902
IDENTIFIED RB PAIR TO BE ADJUSTED; POWER DIFFERENCE BETWEEN TWO ADJACENT RBs SHALL BE SMALLER THAN A THRESHOLD μ
eNB ESTIMATED Rx POWER (dB)
15 dB
μ=12 dB
10 dB
UE_1
UE_2
UE_3
FREQUENCY
1903
ZERO POWER IN ADJACENT SUBCARRIERS; POWER IN OTHER REs REMAIN UNCHANGED
1910
INITIAL TRANSMIT POWER (dB)
UE_1
UE_2
UE_3
FREQUENCY
eNB TRANSMIT POWER ALLOCATION
1904
ZERO RX POWER IN ADJACENT SUBCARRIERS
eNB ESTIMATED Rx POWER (dB)
μ=12 dB
10 dB
UE_1
UE_2
UE_3
FREQUENCY
eNB ESTIMATE OF UE_2 RECEIVE POWER DISTRIBUTION

FIG. 19

NETWORK ASSISTED INTERFERENCE MITIGATION

CROSS-REFERENCE TO RELATED APPLICATION(S) AND CLAIM OF PRIORITY

[0001] The present application claims priority to U.S. Provisional Patent Application Ser. No. 61/841,080, filed Jun. 28, 2013, entitled "NETWORK ASSISTED MITIGATION OF INTER-CARRIER INTERFERENCE (ICI) AND INTER-SYMBOL INTERFERENCE (ISI)". The content of the above-identified patent document is incorporated herein by reference.

TECHNICAL FIELD

[0002] The present application relates generally to wireless communication systems and, more specifically, to a network assisted interference mitigation within wireless communication systems.

BACKGROUND

[0003] Cell-specific reference signals (CRS) and user equipment (UEs) or channels whose decoding relies on CRS are transmitted via a beam having a wide beamwidth, while the Physical Downlink Shared Channel (PDSCH) that relies on demodulation reference signal (DM-RS) can be transmitted via a beam having a narrow beamwidth. Therefore, the received power across resource elements (REs) in a UE can include high power dynamic range (for example, low power at CRS (and its sequential UEs or channels) and high power at DM-RS (its sequential PDSCH)). CRS and UEs or channels (e.g., physical broadcast channel, Physical Broadcast Channel (PBCH), or control channels) relying on CRS may not be received properly in the presence of frequency error, namely carrier frequency offset (CFO), if inter carrier interference (ICI) from substantially higher power PDSCH is intolerable.

SUMMARY

[0004] To address the above-discussed deficiencies of the prior art, it is a primary object to provide a method, apparatus, and system for network assisted interference mitigation in a wireless communication network.

[0005] A method for network assisted interference mitigation is provided. The method includes identifying at least one pair of adjacent resource elements within a same subframe. The at least one pair includes a lower power resource block (RB) and a higher power RB. The lower power RB has lower power than the higher power RB such that a ratio (R) comparing receive powers of the higher power RB and the lower power RB to each other is greater than a threshold ratio (μ). The method includes reducing a transmit power of the higher power RB to a reduced transmit power level at which the ratio R is less than or equal to the threshold ratio μ (R≤μ).

[0006] A base station includes processing circuitry and a transmitter. The processing circuitry is configured to identify at least one pair of adjacent resource elements within a same subframe. The at least one pair includes an unprecoded resource block (RB) and a precoded RB. The unprecoded RB has a substantially lower beamforming gain compared to the high beamforming gain of the precoded RB such that a ratio (R) comparing receive powers of the precoded RB and the unprecoded RB to each other is greater than a threshold ratio (μ). The processing circuitry is also configured to reduce a transmit power of the precoded RB to a reduced transmit power level at which the ratio R is less than or equal to the threshold ratio μ (R≤μ). The transmitter is configured to transmit a signal using the reduced transmit power level.

[0007] A method includes identifying at least a first subframe (k). Each identified subframe includes a first resource block (RB) having high beamforming gain. The method includes configuring an advanced user equipment (UE) whether to expect a resource element guarding pattern to be ON or OFF in each RB in the first subframe.

[0008] Before undertaking the DETAILED DESCRIPTION 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

[0009] 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:

[0010] FIG. **1** illustrates a wireless network **100** that performs a network assisted interference mitigation process according to the embodiments of the present disclosure;

[0011] FIGS. **2**A and **2**B illustrate example wireless transmit and receive paths according to this disclosure;

[0012] FIG. **3** illustrates an example of a base station communicating with legacy UEs and advanced UEs in close spatial proximity to the legacy UEs according to embodiments of the present disclosure;

[0013] FIG. **4** illustrates a graphical example of coexistence of narrow beamwidth-high beamforming gain channels and broad beamwidth-low beamforming gain channels within the same UE according to embodiments of the present disclosure;

[0014] FIG. **5** illustrates an example of ICI resulting from unbalanced RE power and a high power dynamic range according to the present disclosure;

[0015] FIG. **6** illustrates a graph of signal to noise ratio (SNR) versus normalized frequency error (s) for various precoding scenarios according to the present disclosure;

[0016] FIG. **7** illustrates a graphical example of ICI for various subcarriers according to the present disclosure;

[0017] FIGS. **8**A and **8**B illustrate an example of RE guarding by RE muting, where the REs are muted or their power is reduced according to embodiments of the present disclosure;

[0018] FIGS. **9**A and **9** B illustrate examples of performance of RE muting for SNR=10 dB according to embodiments of the present disclosure;

[0019] FIGS. **10**A and **10**B illustrate an example of RE guarding pattern for reducing interference to CSI-RS port;

[0020] FIGS. **11**A and **11**B illustrate examples of guard RE patterns for a FD-MIMO UE in the presence of a legacy UE transmitting two CRS ports according to embodiments of the present disclosure.

[0021] FIGS. **12**A and **12**B illustrate examples of RE guarding pattern for reducing interference to a CSI-RS port according to embodiments of the present disclosure;

[0022] FIGS. **13** and **14** illustrate examples of guard RE patterns of a subframe (k) for high beamforming resource blocks according to embodiments of the present disclosure;

[0023] FIG. **15** illustrates an example fixed RE muting and an example dynamic RE muting according to embodiments of the present disclosure;

[0024] FIG. **16** illustrates an example block diagram of a power control implementation and a RE guarding implementation according to embodiments of the present disclosure;

[0025] FIG. **17** illustrates an example of power control for different channels considering ICI according to embodiments of the present disclosure;

[0026] FIG. **18** illustrates an example of power control for different UEs considering ICI according to embodiments of the present disclosure; and

[0027] FIG. **19** illustrates an example of an RE blanking implementation according to embodiments of the present disclosure.

DETAILED DESCRIPTION

[0028] FIGS. **1** through **19**, 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 communication system.

[0029] This disclosure provides resource element (RE) guarding methods to mitigate the inter-carrier interference (ICI) caused by carrier frequency offset (CFO). Although the present disclosure is disclosed in the context of the cellular band, the embodiments of this disclosure are applicable to other communication media, such as millimeter wave band. For illustration purposes, in this disclosure, the term “cellular band” is used to refer to frequencies around a few hundred megahertz to a few gigahertz, and the term “millimeter wave band” is used to refer to frequencies around a few tens of gigahertz to a few hundred gigahertz. The key distinction is that the radio waves in cellular bands have less propagation loss and can be better used for coverage purpose but may require large antenna size. On the other hand, radio waves in millimeter wave bands suffer higher propagation loss but lend themselves well to high-gain antenna or antenna array design in a small form factor.

[0030] Aspects, features, and advantages of the invention are readily apparent from the following detailed description, simply by illustrating a number of particular embodiments and implementations, including the best mode contemplated for carrying out the invention. The embodiments of this disclosure are also capable of other and different embodiments, and its several details can be modified in various obvious respects, all without departing from the spirit and scope of this disclosure. Accordingly, the drawings and description are to be regarded as illustrative in nature, and not as restrictive. In this disclosure, the figures of the accompanying drawings provide illustrations by way of example, and not by way of limitation. In this disclosure, the figures show a limited number and types of evolved Node B (eNBs) or limited number of UEs or limited number of connections or limited use cases as an example for illustration. However, the embodiments disclosed in this invention are also applicable to various numbers and types of base stations, a various number of mobile stations, a various number of connections, and other related use cases.

[0031] FIG. **1** illustrates a wireless network **100** that performs a network assisted interference mitigation process according to the embodiments of the present disclosure. The embodiment of the wireless network **100** shown in FIG. **1** is for illustration only. Other embodiments could be used without departing from the scope of this disclosure.

[0032] The wireless network **100** includes base station (BS) **101**, base station (BS) **102**, base station (BS) **103**, and other similar base stations (not shown). Base station **101** is in communication with base station **102** and base station **103**. Base station **101** is also in communication with Internet **130** or a similar IP-based network (not shown).

[0033] Base station **102** provides wireless broadband access (via base station **101**) to Internet **130** to a first plurality of mobile stations within coverage area **120** of base station **102**. The first plurality of mobile stations includes mobile station **111**, which can be located in a small business (SB), mobile station **112**, which can be located in an enterprise (E), mobile station **113**, which can be located in a WiFi hotspot (HS), mobile station **114**, which can be located in a first residence (R), mobile station **115**, which can be located in a second residence (R), and mobile station **116**, which can be a mobile device (M), such as a cell phone, a wireless laptop, a wireless PDA, or the like.

[0034] Base station **103** provides wireless broadband access (via base station **101**) to Internet **130** to a second plurality of mobile stations within coverage area **125** of base station **103**. The second plurality of mobile stations includes mobile station **115** and mobile station **116**. As an example, base stations **101-103** communicate with each other and with mobile stations **111-116** using orthogonal frequency division multiple (OFDM) or orthogonal frequency division multiple access (OFDMA) techniques.

[0035] Base station **101** can be in communication with either a greater number or a lesser number of base stations. Furthermore, while only six mobile stations are depicted in FIG. **1**, it is understood that wireless network **100** can provide wireless broadband access to additional mobile stations. It is noted that mobile station **115** and mobile station **116** are located on the edges of both coverage area **120** and coverage area **125**. Mobile station **115** and mobile station **116** each communicate with both base station **102** and base station **103** and can be said to be operating in handoff mode, as known to those of skill in the art.

[0036] Mobile stations **111-116** access voice, data, video, video conferencing, and/or other broadband services via Internet **130**. In an exemplary embodiment, one or more of mobile stations **111-116** is associated with an access point (AP) of a WiFi WLAN. Mobile station **116** can be any of a number of mobile devices, including a wireless-enabled laptop computer, personal data assistant, notebook, handheld device, or other wireless-enabled device. Mobile stations **114** and **115** can be, for example, a wireless-enabled personal computer (PC), a laptop computer, a gateway, or another device.

[0037] FIG. **2**A is a high-level diagram of an orthogonal frequency division multiple access (OFDMA) transmit path. FIG. **2**B is a high-level diagram of an orthogonal frequency division multiple access (OFDMA) receive path. In FIGS. **2**A and **2**B, the OFDMA transmit path is implemented in base station (BS) **102** and the OFDMA receive path is implemented in mobile station (MS) **116** for the purposes of illustration and explanation only. However, it will be understood by those skilled in the art that the OFDMA receive path also can be implemented in BS **102** and the OFDMA transmit path can be implemented in MS **116**.

[0038] The transmit path in BS **102** includes channel coding and modulation block **205**, serial-to-parallel (S-to-P) block **210**, Size N Inverse Fast Fourier Transform (IFFT) block **215**, parallel-to-serial (P-to-S) block **220**, add cyclic prefix block **225**, up-converter (UC) **230**. The receive path in MS **116** comprises down-converter (DC) **255**, remove cyclic prefix block **260**, serial-to-parallel (S-to-P) block **265**, Size N Fast Fourier Transform (FFT) block **270**, parallel-to-serial (P-to-S) block **275**, channel decoding and demodulation block **280**.

[0039] At least some of the components in FIGS. **2**A and **2**B can be implemented in software while other components can be implemented by configurable hardware or a mixture of software and configurable hardware. In particular, it is noted that the FFT blocks and the IFFT blocks described in this disclosure document can be implemented as configurable software algorithms, where the value of Size N can be modified according to the implementation.

[0040] In BS **102**, channel coding and modulation block **205** receives a set of information bits, applies LDPC coding and modulates (e.g., QPSK, QAM) the input bits to produce a sequence of frequency-domain modulation symbols. Serial-to-parallel block **210** converts (i.e., de-multiplexes) the serial modulated symbols to parallel data to produce N parallel symbol streams where N is the IFFT/FFT size used in BS **102** and MS **116**. Size N IFFT block **215** then performs an IFFT operation on the N parallel symbol streams to produce time-domain output signals. Parallel-to-serial block **220** converts (i.e., multiplexes) the parallel time-domain output symbols from Size N IFFT block **215** to produce a serial time-domain signal. Add cyclic prefix block **225** then inserts a cyclic prefix to the time-domain signal. Finally, up-converter **230** modulates (i.e., up-converts) the output of add cyclic prefix block **225** to RF frequency for transmission via a wireless channel. The signal can also be filtered at baseband before conversion to RF frequency.

[0041] The transmitted RF signal arrives at MS **116** after passing through the wireless channel and reverse operations to those at BS **102** are performed. Down-converter **255** down-converts the received signal to baseband frequency and remove cyclic prefix block **260** removes the cyclic prefix to produce the serial time-domain baseband signal. Serial-to-parallel block **265** converts the time-domain baseband signal to parallel time domain signals. Size N FFT block **270** then performs an FFT algorithm to produce N parallel frequency-domain signals. Parallel-to-serial block **275** converts the parallel frequency-domain signals to a sequence of modulated data symbols. Channel decoding and demodulation block **280** demodulates and then decodes (i.e., performs LDPC decoding) the modulated symbols to recover the original input data stream.

[0042] Each of base stations **101-103** implement a transmit path that is analogous to transmitting in the downlink to mobile stations **111-116** and implement a receive path that is analogous to receiving in the uplink from mobile stations **111-116**. Similarly, each one of mobile stations **111-116** implement a transmit path corresponding to the architecture for transmitting in the uplink to base stations **101-103** and implement a receive path corresponding to the architecture for receiving in the downlink from base stations **101-103**.

[0043] The channel decoding and demodulation block **280** decodes the received data. The channel decoding and demodulation block **280** includes a decoder configured to perform a network assisted interference mitigation operation.

[0044] In future wireless communication, extremely directional beamforming can be implemented e.g. via full-dimension multiple input multiple output (FD-MIMO) or fifth generation (5G) millimeter wave (mmWave) to improve the spectrum efficiency and to enable high order multiple user MIMO (MU-MIMO). Such precoding or beamforming is supported by non-codebook based precoding in 3GPP LTE-Advanced standards, and does not require signaling of the precoders as long as the same precoders are applied to the demodulation reference signal (DM-RS). Meanwhile, cell-specific reference signals (CRS) and user equipment (UEs) or channels (e.g., physical broadcast channel (PBCH), or control channels) relying on CRS cannot be transmitted via narrow beams, otherwise they cannot be received properly. Some resource elements (REs) are precoded or narrowly beamformed and thus have extremely high power, while some other REs are transmitted via wide beam and thus have small power. As a result, UEs may potentially operate with a high dynamic range of power.

[0045] FIG. **3** illustrates an example of a base station communicating with legacy UEs and advanced UEs in close spatial proximity to the legacy UEs according to embodiments of the present disclosure. The embodiment shown in FIG. **3** is for illustration only. Other embodiments could be used without departing from the scope of this disclosure.

[0046] FIG. **3** shows an example of advanced UEs **311** and **312** that support FD-MIMO operation communicating with a same cell as legacy UEs **321** and **322** that rely on CRS to decode Physical Downlink Control Channel (PDCCH) or estimate the channel followed by decoding. The base station **301** communicates with the advanced UEs **311-312** by transmitting signals **320** with precoding using UE-specific beamforming. The base station **301** communicates with the legacy UEs **321-322** by transmitting a signal **330** without precoding using cell-specific beamforming. When advanced UEs **311-312** are in close physical proximity to the legacy UEs **321-322**, the legacy UEs may receive strong power in the REs assigned to advanced UEs **311-312** due to the correlation among their channels. In this case, the high power beamforming operation of advanced UEs **311-312** may cause severe interference to the legacy UEs **321-322**.

[0047] FIG. **4** illustrates a graphical example of coexistence of narrow beamwidth-high beamforming gain channels and broad beamwidth-low beamforming gain channels within the same UE according to embodiments of the present disclosure. The embodiment shown in FIG. **4** is for illustration only. Other embodiments could be used without departing from the scope of this disclosure.

[0048] Specifically, a UE's PDSCH channel is precoded with narrow beamforming that may lead to a high receive power, while the UE's PBCH channel and synchronization signals (e.g., Primary Synchronization Signal (PSS) or Secondary Synchronization Signal (SSS)) are transmitted with wide beamwidth that may lead to a low power. This UE may receive a high dynamic range of power, namely, the received power of the narrow beamwidth-high beamforming gain PDSCH is (for example, 20 decibels (dB)) greater than the broad beamwidth-low beamforming gain channels. The high receive power of the precoded or high power channel may severely interfere with the low power channels of the UE. New methods are needed to ensure all (advanced UEs **321-322** and legacy UEs **311-312**) the UEs or channels can be received properly.

[0049] Inter-carrier interference (ICI) is one of the problems of a UE having a high power dynamic range. Most of wireless systems rely on orthogonal frequency division multiplexing (OFDM) and are subject to frequency error and inter-carrier interference (ICI). UEs are subject to frequency error caused by Doppler, phase noise and inaccuracy of local oscillators. Frequency error (namely, carrier frequency offset (CFO)) causes ICI. In the presence of CFO, the received signal at the kth subcarrier can be expressed by Equation 1:

$$y_k = X_k S_O + \Sigma_{l=0, l \neq k}{}^{N-1} S_{l-k} X_l + n_k, \text{ for } k = 0, 1, \ldots, N-1. \tag{1}$$

where X_k is the high power signal in the kth subcarrier, N is the total number of subcarriers and the terms in the summation are interference. In Equation 1,

$$S_k = \frac{\sin \pi (k+\varepsilon)}{N \sin \frac{\pi}{N} (k+\varepsilon)} e^{-j\pi\left(1-\frac{1}{N}\right)(k+\varepsilon)} \tag{2}$$

The value of S_k depends on the value of a normalized CFO (ϵ). Typically, in LTE systems (or any OFDM based systems) ϵ must be maintained sufficiently small so that the degradation of interference is tolerable. Current 3GG RAN **4** specifies a UE shall have frequency accuracy of ±0.1 PPM (i.e., $\pm 10^{-7}$), which corresponds to ϵ shown in Table 1.

TABLE 1

Normalized frequency error under different carrier frequency and subcarrier spacing

Carrier Freq. (GHz)	Freq. error (Hz)	Normalized Freq. error (ϵ)	Subcarrier space (kHz)
2	200	1.3%	15
3.5	350	2.3%	15
28	2800	1.8%	150
60	6000	4%	150

[0050] In cases of a high power dynamic range, the requirement of ±0.1 PPM may not be sufficient to prevent severe interference. For example, a legacy UE, such as UE **321-322**, can tolerate a $\epsilon \leq 1\%$, which means that for a 15 kHz subcarrier space, the frequency error must not exceed 150 Hz, yet under the 3GG RAN **4** specification, a 2 GHz carrier frequency corresponds to s=1.3% and frequency error of 200 Hz (i.e., $\pm 10^{-7} \times 2 \times 10^9$ Hz=±200 Hz), which may be intolerable to the legacy UE. FIG. **5** illustrates an example of ICI resulting from unbalanced RE power and a high power dynamic range according to the present disclosure. The subcarrier X_k (e.g., CRS RE) is low powered, and the adjacent REs (X_{k-1}, X_{k+1}) are high powered. In this disclosure, the term high power refers to a resource element having high beamforming gain; and the term low power refers to a resource element having low beamforming gain. At the receiver side, the power of the received signal of the low power subcarrier X_k is substantially less than the received power of an adjacent subcarrier ($X_{k\pm1} >> X_k$) that is a high power RE. Even with small ϵ the ICI experienced by the subcarrier X_k is significant. For example, the amount of received power of the interference leaked from adjacent subcarriers (X_{k-1} and X_{k+1}) is nearly as much as the amount of received power of the CRS RE signal itself. In this case, even if only a small percentage of power is leaked from (X_{k-1}, X_{k+1}), the leakage causes significant interference to X_k, as the signal-to-noise-and-interference (SINR) ratio may be too low for reliable decoding for the information carried in the subcarrier X_k. Such degradation may introduce significant throughput loss for the UEs relying on CRS to decode or estimate its channel, and thus must be accounted for and mitigated effectively. The amount of received power of the interference leaked from the low power subcarrier (X_k) is significantly less than the amount of received power of the individual FD MIMO PDSCH REs.

[0051] FIG. **6** illustrates a graph of signal to noise ratio (SNR) versus normalized frequency error (c) for various precoding scenarios according to the present disclosure. The embodiment shown in FIG. **6** is for illustration only. Other embodiments could be used without departing from the scope of this disclosure.

[0052] The graph **600** shows SNR degradation in the presence of precoding and quantifies the impact of frequency error under evenly distributed power and high power dynamic range. Three scenarios are shown, including a scenario of no precoding, a scenario of precoding using sixty-four (64) transmit antennas, and a scenario of precoding using eight (8) transmit antennas. In case of no precoding (shown as a hollow circle marked curve), the an equal amount of power is transmitted to the REs, and the SNR degradation is less than 0.3 dB even if ϵ=4%. In the presence of precoding (shown as a hollow triangle marked curve) with 8 antennas (a beamforming gain 8 times), the SNR degradation for low power REs is 1.5 dB when ϵ=4% and 0.7 dB when ϵ=2.5%. When the number of transmit antennas is 64 (e.g., FD-MIMO or mmWave) (maximum 64 times beamforming gain), the SNR degradation for low power REs is 3.5 dB when ϵ=2.5%, much more severe than current **8** antenna LTE system or low power system. Degradation of the SNR increases significantly with an increase in beam forming gain (i.e., increase in number of transmit antennas).

[0053] FIG. **7** illustrates a graphical example of ICI for various subcarriers according to the present disclosure. The embodiment shown in FIG. **7** is for illustration only. Other embodiments could be used without departing from the scope of this disclosure.

[0054] In FIG. **7**, the coefficient S_k is plotted where ϵ=2%. The graph **700** show normalized power coefficient (S_k) versus subcarrier index. The subcarrier index (k) for a subcarrier of interest is zero (i.e., k=0), and the adjacent subcarrier indices are positive and negative one (i.e., k=1 and k=−1). For simplicity, subcarrier of interest ($X_{k=0}$) is not shown in the graph, yet only positive subcarrier indices are shown. The negative subcarrier indices are a mirror image reflection of the positive subcarrier indices. That is, the normalized power coefficient for subcarrier indicies −1, −2, and −3 are the equivalent to the normalized power coefficient for subcarrier indices 1, 2, and 3, respectively. As shown, the S_k of adjacent REs ($X_{k=1}$ and $X_{k=-1}$) dominates over REs that are non-adjacent and further away ($X_{k\pm2}$ and $X_{k\pm3}$). From the amount of interference leaked decays exponentially as the further way an interfering subcarrier is located from the subcarrier of interest. That is, subcarrier X_0 receives exponentially less interference from subcarrier X_3 than from X_2. Also, subcarrier X_0 contributes exponentially more interference to subcarrier X_2 than to X_3.

Network Assisted Interference Mitigation

[0055] In this disclosure, the base-station **301** configures the power allocation of different UEs so that the interference will be reduced at the UE side. For example, the base-station can mute (or reduced the power) the high power REs adjacent to a low power RE. The graph **700** shows that most of the interference (approximately 50%) is from the adjacent REs (i.e., subcarrier indices 1 and −1). Accordingly, limiting the power of the adjacent REs will effectively reduce the interference received at the RE of interest (X_k). A guard band in the time domain will reduce interference.

[0056] FIGS. **8**A and **8**A illustrates an example of RE guarding by RE muting, where the REs are muted or their power is reduced according to embodiments of the present disclosure. The embodiments of the RE guarding by RE muting shown in FIGS. **8**A and **8**B are for illustration only. Other embodiments could be used without departing from the scope of this disclosure. FIG. **8**A illustrates amounts of power of transmitted signals for various subcarriers. FIG. **8**B illustrates amounts of power of received signals for various subcarriers, where the received signals where transmitted in FIG. **8**A.

[0057] At the transmitter side, the two high power REs **810** and **820** adjacent to the low power (e.g., CRS) REs **800** are muted, (e.g., setting power to be zero). At the receiver side, because of the precoding, the low power CRS RE's **805** power level is much lower than the power level of high power REs **815** and **825**. Because the two adjacent REs are muted, no interference is caused by the adjacent REs; only the REs **835**, **845**, **855**, **865** that are further away ($X_{k\pm2}$ and $X_{k\pm3}$) will cause interference, which is small according to FIG. **7**. That is, the normalized power coefficient values (S_k) of FIG. **7** can represent power levels of the subcarriers in FIGS. **8**A and **8**B.

[0058] The amount of power of the received signal **805** for subcarrier X_k is the sum of power received from the low power (shown in light shading) transmitted signal **800**, the power received from the interference leaked from the high power (shown in dark shading) received signals **835**, **840**, **850**, and **860**. For subcarrier X_k, the received power of attributable to the low power signal is substantially greater than the received power attributable to leakage from the high power signals.

[0059] The amount of power of the received signal **835** for subcarrier X_{k-1} is the sum of power received from the high power (shown in dark shading) transmitted signal **830**, the power received from the interference leaked from the low power (shown in light shading) received signal **805**. For subcarrier X_{k-1}, the received power of attributable to the high power signal **830** is substantially greater than the received power attributable to leakage from the low power signal **805**. Also, as the low power subcarrier X_k is non-adjacent and further from the subcarrier X_{k-2} than from subcarrier X_{k-1}, the amount of interference leaked from X_k to X_{k-1} is exponentially greater than the amount of interference leaked from X_k to X_{k-2}.

[0060] FIGS. **9**A and **9** B illustrate examples of performance of RE muting for SNR=10 dB according to embodiments of the present disclosure. The embodiments of RE muting shown in FIGS. **9**A and **9**B are for illustration only. Other embodiments could be used without departing from the scope of this disclosure

[0061] FIG. **9**A illustrates a graph of signal to noise ratio (SNR) for 8 transmit antennas versus normalized frequency error (ϵ) for various precoding and RE guarding scenarios. FIG. **9**A illustrates a graph of signal to noise ratio (SNR) for 64 transmit antennas versus normalized frequency error (ϵ) the same precoding and RE guarding scenarios as FIG. **9**A. Three scenarios are shown, including a scenario of no precoding, a scenario of precoding without using RE guarding, and a scenario of precoding using RE guarding.

[0062] A comparison of FIG. **6** to FIGS. **9**A and **9**B shows that RE guarding considerably reduces the interference and SNR loss, where adjacent REs are muted. At 2.5% CFO, the RE guarding by RE muting according to the present disclosure obtains SNR gain 0.4 dB with 8 transmit antennas, and in the range of 1.8 dB to 2 dB with 64 transmit antennas. At ϵ=4.0%, the RE muting according to embodiments of this disclosure obtains SNR gains in the range of 0.9 dB to 1.0 dB with 8 transmit antennas, and in the range of 2.6 to 2.8 dB with 64 transmit antennas. As the number of antennas increases, the SNR gain of RE guarding viability increases. RE guarding by muting adjacent REs can provide approximately 3 dB of gain.

[0063] Embodiments of the present disclosure are simple and do not require complex UE or eNB processing, compared with other methods. For example, in frequency equalization methods, a UE has to apply a complex algorithm to equalize the channels to reduce the interference. Another method is self-cancellation, which requires an eNB to know the channel response in advance to pre-equalize the channel. Benefits of embodiments of the present disclosure can be realized and implemented without impacting the current standards.

RE Guarding Pattern

[0064] FIGS. **10**A and **10**B illustrate an example of guard RE patterns for an advanced UE in the presence of a legacy UE transmitting one CRS port according to embodiments of the present disclosure. The embodiments of the guard RE patterns shown in FIGS. **10**A and **10**B are for illustration only. Other embodiments could be used without departing from the scope of this disclosure.

[0065] The base station **301** reduces the power or completely mutes some REs (called guard REs) in a resource block (RB) so that the ICI to other REs may be reduced. The proposed method is named as RE guarding. There is a tradeoff between the ICI reduction (SINR gain) by RE guarding and the overall system throughput. In this disclosure, the REs that used to carry information are now selected as guard REs and they are either muted (transmitted at zero power) or carry reduced power signals.

[0066] The selection of guard REs requires careful designs as it will reduce the data rate that can be carried by RB. Within a RB, the base station **301** selects a few REs as guard REs, time-frequency mapping of the selected guard REs within a RB is called a "RE guarding pattern." An increase in the number of REs to be included in a RE guarding pattern cause less ICI (and higher SINR) for the other REs in this RB.

[0067] RE guarding may primarily apply to DM-RS port(s) transmission. For example, when an eNB is transmitting

PDSCH on a DM-RS port (e.g., 3GPP LTE downlink antenna port 7/8 for an advanced UE), the eNB may use the RE guarding, so that the interference to CRS RE received at another UE can be reduced.

[0068] FIGS. **10**A and **10**B show RE guarding patterns for reducing interference to a CRS port. In a case of 1 CRS port, two RB patterns can be considered. FIG. **10**A illustrates a first RB pattern **1000** (1P−1) that includes two adjacent REs (dark-shaded) for every CRS REs (light shaded, marked with a value R_0). FIG. **10**B illustrates a second pattern **1001** (1P−2) that only includes 1 adjacent RE (dark-shaded) for every CRS REs (light shaded, marked with a value R_0). With the pattern **1000** (1P−1), ICI is smaller than that in pattern **1001** (1P−2), but the pattern **1000** (1P−1) has higher loss in available REs for PDSCH. In practice, the base station **301** can choose among two patterns depending on the requirement on interference as well as the overall throughput requirement.

[0069] FIGS. **11**A and **11**B illustrate examples of guard RE patterns for an advanced UE in the presence of a legacy UE transmitting two CRS ports according to embodiments of the present disclosure. The embodiments of the guard RE patterns shown in FIGS. **11**A and **11**B are for illustration only. Other embodiments could be used without departing from the scope of this disclosure.

[0070] In a case of 2 CRS ports, two patterns are considered. FIG. **11**A illustrates the first pattern **1100** (2P−1) that includes one adjacent (dark-shaded) REs for every CRS RE (light shaded, marked with a value R_0 for a first CRS port and marked with a value R_1 for a second CRS port). In the first pattern **1100**, RB pattern **1100***a* for the CRS REs of the first CRS port (light shaded, marked with a value R_0) are not used for transmission on the antenna port in the RB pattern **1101***b* for the second CRS port. Vice versa, in the second pattern **1101**, the REs (marked R_1 for the value within the resource element) used for transmission in RB pattern **1101***a* are not used for transmission in the RB pattern **1101***b*.

[0071] FIG. **11**B illustrates the second pattern **1101** (2P−2), where the base station **301** mutes one RE (dark-shaded) for every CRS port 1 and CRS port 2 in OFDM symbol **0**, **7** and **4**, **11**, respectively. It is a technical advantage to provide multiple choice to balance the ICI reduction and data RE loss. The first CRS port is transmitted according to the RB pattern **1101***a*; and the second CRS port is transmitted according to the RB pattern **1101***b*, where certain REs (cross hatched) are not used for transmission on the antenna port used to transmits the CRS port 1 (light shaded, marked R_0). Information throughput is reduced corresponding to the REs that are not used for transmission.

[0072] FIGS. **12**A and **12**B illustrate examples of RE guarding pattern for reducing interference to a CSI-RS port according to embodiments of the present disclosure. The embodiments of the guard RE patterns shown in FIGS. **12**A and **12**B are for illustration only. Other embodiments could be used without departing from the scope of this disclosure. The base station **301** guards RE patterns for an advanced UE in the presence of a legacy UE transmitting via a CSI-RS port.

[0073] In case of CSI-RS port transmission, CSI-RS ports can be low power. Using the similar RE muting principles for CRS case, FIGS. **12**A and **12**B show two patterns that provide multiple choices to balance the interference reduction and data RE loss. In FIG. **12**A, the first pattern **1200** (CSI-1) includes two adjacent (dark shaded) RES for every CSI RE (light shaded, marked with a value R_{15}-R_{23}). In FIG. **12**B, the second pattern **1201** (CSI-2) includes one adjacent (dark shaded) RES for every CSI RE (light shaded, marked with a value R_{15}-R_{23}).

[0074] FIGS. **13** and **14** illustrate examples of guard RE patterns of a subframe (k) for high beamforming resource blocks according to embodiments of the present disclosure. The embodiments of the guard RE patterns shown in FIGS. **13** and **14** are for illustration only. Other embodiments could be used without departing from the scope of this disclosure.

[0075] The guard RE patterns in FIGS. **13** and **14** are applicable to the cases where one side of the low power RBs is adjacent to the high power RBs or both sides of the low power RBs are adjacent to the high power RBs. Regarding RE guarding patterns for PBCH and other channels: when broad beamwidth-low beamforming gain PBCH/ePDCCH/PDSCH is transmitted along with narrow beamwidth-high beamforming gain PDSCH, the base station **301** selects to mute or reduce power of the subcarriers in the boundary of the high power RBs to the low power RBs. That is, the base station **301** mutes or reduces the power for a subset of REs adjacent to some reference signals (e.g., CRS, CSI-RS). The guard RE patterns of the present disclosure mitigate interference for signals having critical reference elements transmitted to legacy UEs, improves reception based on CRS of legacy UEs in close proximity to advanced UEs, and improves channel measurement based on CSI-RS of legacy UEs in close proximity to advanced UEs. The guard RE patterns protect legacy UEs from severe interference attributable to proximity to advanced UEs **311-312**.

[0076] FIG. **13** illustrates a subframe of a single UE having a guard RE pattern for one-sided high beamforming RBs. The subframe **1300** (*k*) includes a low power resource block **1310** (for example, PBCH, ePDCCH, or PDSCH) having two adjacent resource blocks that have low and high beamforming gains. Applicable examples include when PBCH reception is co-scheduled with precoded PDSCH; the ePDCCH reception is co-scheduled with precoded PDSCH; the unprecoded PDSCH reception is co-scheduled with precoded PDSCH for other UES; or the PSS detection is in FDD. On one side, the low power resource block **1310** is adjacent to the RB **1320** with high beamforming gain. On the other side, the low power resource block **1310** is adjacent to the RB **1330** with low beamforming gain. For example, RB **1320** is on the higher frequency side of the low power resource block **1310**, and RB **1330** is on the lower frequency side of RB **1310**. Within the RB **1320** with high beamforming gain, the boundary high power resource elements **1340** that are adjacent to the low power RB **1310** can cause severe interference to the boundary low power resource elements within the RB **1310**. The base station **301** implements a RE guard pattern for the low power channel by muting or reducing the power of boundary high power resource elements **1340** that are adjacent to the low power RB **1310**.

[0077] FIG. **14** illustrates a subframe having a guard RE pattern for two-sided high beamforming RBs. The subframe **1400** shows the cases where both sides of the low power RBs **1410** are adjacent to the high power RBs **1420** and **1430** with high beamforming gains. For example, high power RB **1420** is on the higher frequency side of the low power resource block **1410**, and high power RB **1430** is on the lower frequency side of RB **1410**. The base station **301** implements a RE guard pattern for the low power channel by muting or reducing the power of boundary high power resource elements **1440** that are adjacent to the REs of the higher frequency side of the low power RB **1410**, and by muting or reducing the power of boundary high power resource elements **1445** that are adjacent to the REs of the lower frequency side of the low power RB **1410**.

eNB Configurations of Guard RE Pattern

[0078] FIG. **15** illustrates an example fixed RE muting and an example dynamic RE muting according to embodiments of the present disclosure. The embodiment of the RE muting shown in FIG. **15** is for illustration only. Other embodiments could be used without departing from the scope of this disclosure.

[0079] The subframe **1500** (X_k) includes resource blocks **1510** for communication with advanced UEs. For example, the RBs **1510** can be precoded (dark shading) with high beam forming gain and subject to having RE muting applied. The higher frequency side of the RBs **1510** is adjacent to RBs **1520** without reference elements for communication with advanced UEs. The lower frequency side of the RBs **1510** is adjacent to RBs **1530** without reference elements for communication with advanced UEs. For example, the RBs **1520** and **1530** can be unprecoded (light shading) and not subject to having RE muting applied.

[0080] The subframe **1501** (X_k+$_1$) includes resource blocks **1511** for communication with advanced UEs. For example, the RBs **1511** can be precoded (dark shading) with high beam forming gain, but not subject to having RE muting applied. The higher frequency side of the RBs **1511** is adjacent to RBs **1521** without reference elements for communication with advanced UEs. The lower frequency side of the RBs **1511** is adjacent to RBs **1531** without reference elements for communication with advanced UEs. For example, the RBs **1521** and **1531** can be unprecoded (light shading) and not subject to having RE muting applied. That is, no RE muting is applied in subframe **1501** (X_{k+1}).

[0081] The base stations **301** of present disclosure not only implement RE muting within a guard RE pattern, but also implement RE power reduction. RE muting can be applied to a variety of RE guarding configurations, including: semi-static RE muting configurations, and dynamic RE muting configurations. RE power rejection can be applied alone or in jointly with RE muting.

[0082] In one example, when an advanced UE is scheduled with a FD-MIMO transmission scheme, RE guarding is applied to the corresponding PDSCH. In subframe **1500** (X_k), for all the RBs that are assigned to one or more advanced UEs, one of the RE guarding patterns specified in FIGS. **10**A-**12**B is applied.

[0083] In another example, eNB **301** can configure whether or not an advanced UE (for example, advanced UEs **311** or **312**) should expect RE guarding for FD-MIMO PDSCH.

[0084] In another example, eNB **301** can indicate 2-bit information to an advanced UE regarding which one of 3 different patterns is selected for RE guarding. For example, the three different patterns can include a CRS port 1 guard pattern, a CRS port 2 guard pattern, and CSI-RS port 1 guard pattern.

[0085] These semi-static configurations can be configured by a higher layer (e.g., RRC). Semi-static RE guarding configurations can change from REs from a muted state to an unmuted state in approximately 1 second. Dynamic RE guarding configurations can change from REs from a muted state to an unmuted state in approximately a millisecond, which is 1000 times faster than semi-static configurations. More specifically, the methods for implicit configuration include: (1) an implicit configuration by transmission scheme, or (2) an implicit configuration by transmission mode. In the case of implicit configuration by transmission scheme, an advanced UE assumes RE guard pattern is transmitted is a certain transmission scheme is scheduled. In the case of implicit configuration by transmission mode, an advanced UE assumes RE guard pattern is transmitted is a certain transmission mode is configured.

[0086] The methods for explicit RRC configuration include: (1) one bit to indicate whether RE muting is ON or OFF, or (2) two bits to indicate whether RE muting is on or off, and if on, which pattern is used. Using a one bit indicator, for example, 0 indicates that RE guard pattern is not used, and 1 indicates that RE guard pattern is used. Using a two bit indicator, for example, Table 2 defines which pattern is used, if any.

TABLE 2

2-bit RE Muting Indication

State of the 2-bit field	CRS port 1	CRS port 2	CSI-RS port
00	Off	Off	Off
01	1P-1 in FIG. 10A	2P-1 in FIG. 11A	CSI-1 in FIG. 12A
10	1P-2 in FIG. 10B	2P-2 in FIG. 11B	CSI-2 in FIG. 12B
11	reserved	reserved	reserved

[0087] In dynamic configurations: in one example, eNB **301** can indicate 1-bit information to an advanced UE regarding whether or not an advanced UE should expect RE guarding for FD-MIMO PDSCH. This indication can be signaled dynamically in a DCI format.

[0088] In another example, eNB **301** can signal 2-bit information (e.g., as in Table 2) to an advanced UE to indicate which one of three different RE guarding patterns that the UE should expect. This indication can be signaled dynamically in a DCI format.

[0089] The dynamic configurations improve the spectrum efficiency by reducing the number of subframes applying RE muting. That is, instead of completely muting the REs according to the patterns in FIGS. **10**A-**12**B, the base station **301** implements RE power reduction methods such that the powers of these guard REs are reduced and the ratio of the powers are configured.

[0090] In the case of RE Power Reduction alone, for the advanced UE, the power of the guard REs in the RE guard patterns are reduced by a certain dB with respect to the other PDSCH REs in the RB. The power reduction in dB can be signaled according to Table 3, where these two bits information can be signaled via a higher layer.

TABLE 3

RE Power reduction indication

State of the 2-bit field	Power ratio of guard REs to the other PDSCH REs (dB) - Alt 1	Power ratio of guard REs to the other PDSCH REs (dB) - Alt 2
00	0	−3
01	−3	−6
10	−6	−9
11	−9	−∞ (the guard REs are muted)

[0091] In the case of Joint RE Muting and Power Reduction, a 2-bit field indicates a selected RE guarding pattern as well as a RE power level. Two examples of such indication are provided below in Tables 4 and 5. Table 4 is an example of the joint indication for the case of 1 CRS port. Table 5 is an example of the joint indication for the case of 2 CRS ports.

TABLE 4

Joint RE guarding pattern and power reduction indication (1 CRS port)

State of the 2-bit field	Power ratio of guard REs to the other PDSCH REs (dB)	RE guard pattern
00	−3	1P-2
01	−6	1P-2
10	−9	1P-1
11	−∞ (the guard REs are muted)	1P-1

TABLE 5

Joint RE guarding pattern and power reduction indication (2 CRS ports)

State of the 2-bit field	Power ratio of guard REs to the other PDSCH REs (dB)	RE guard pattern
00	−3	2P-2
01	−6	2P-2
10	−9	2P-1
11	−∞ (the guard REs are muted)	2P-1

[0092] Tables 3 and 4 show that: if a denser RE guarding pattern is used, the legacy UEs may suffer from severe ICI so that the base station **301** needs to reduce more power for guard REs. On the other hand, if a less dense RE guarding pattern is used, the legacy UEs may suffer from mild ICI so that the base station **301** may not need to reduce much power for guard REs.

eNB Implementation by Considering Guard RE Pattern

[0093] The impact of interference in the presence of high power dynamic range can also be mitigated by some specific eNB implementations without changing the current 3GPP LTE standard. These specific eNB implementations include a power control implementation, and an RE blanking implementation.

[0094] In the power control implementation the eNB reduces transmit power used for some selected RBs, which may have a much higher receive power at a UE compared with adjacent RBs that carry desired information for the UE. By reducing the transmit power of the selected RBs, the receive power dynamic range across RBs can be reduced, improving the robustness for interference avoidance.

[0095] FIG. **16** illustrates an example block diagram of a power control implementation and a RE guarding implementation according to embodiments of the present disclosure. While the flow chart depicts a series of sequential steps, unless explicitly stated, no inference should be drawn from that sequence regarding specific order of performance, performance of steps or portions thereof serially rather than concurrently or in an overlapping manner, or performance of the steps depicted exclusively without the occurrence of intervening or intermediate steps. The process depicted in the example depicted is implemented by a transmitter chain in, for example, a base station. All the decision blocks are used in the implementations (for example, checking whether two RBs belong to the same UE/channel).

[0096] In block **1605**, the eNB receives a UE's feedback report on channel quality indicator (CQI) and precoding matrix indicator (PMI) (in frequency division duplexing (FDD)) or estimating uplink channels based on SRS sounding signals (in time division duplexing (TDD)). The eNB calculates MCS level based on PMI (or SRS channel estimation), CQI and power allocation for UEs. The eNB estimates received power for all RBs from the UE's perspective. The power is denoted as P_1, where the RB index or counter is i=1, . . . , N and N is the total number of RBs in use, and where the user index or counter is U and U is the total number of UEs within the cell of the eNB.

[0097] In block **1610**, the eNB identifies all pairs of consecutive 2 RBs $\{P_{i,u}, P_{i+1,\,u}\}_k$, where

$$\frac{P_{i,u}}{P_{i+1,u}} > \mu \text{ or } \frac{P_{i+1,u}}{P_{i,u}} > \mu.$$

The total number of pairs is K, and the count of pairs is initialized as k=1. In block **1610**, the eNB identifies the problematic RB pairs, where adjacent RBs have an intolerable power dynamic range.

[0098] In block **1615**, the eNB determines whether the current pair of RBs is the last of the total number (K) of consecutive RBs. If the count (k) for the current pair of RBs is not the last pair, then the method continues to block **1620**. If the eNB determines that the count (k) for the current pair of RBs is the last pair, then the method continues to block **1625**, where the eNB increments the UE counter (u) by one (i.e., u=u+1).

[0099] In block **1620**, the eNB analyzes the k^{th} pair of consecutive RBs by determining whether the RB with higher power relies on DM-RS. If the RB with higher power relies on DM-RS (e.g., a critical reference signal relied upon by advanced UEs), then the method continues to block **1630**. Else, the method continues to block **1635**, where the index counter (k) is incremented by one (k=k+1) and then returns to block **1615**. In block **1620**, the eNB determines whether the u^{th} UE is an advance UE, such as UE **311-312**, or a legacy user equipment, such as UE **321-322**. The method continues from block **1620** to block **1635** upon a determination that the u^{th} UE is legacy UE.

[0100] In block **1630**, the eNB determines whether the k^{th} pair of consecutive RBs belong to at least two UEs or at least two channels. If so, the method continues to block **1640**. If not, the method continues to block **1635**, where the index counter (k) is incremented by one (k=k+1) and then returns to block **1615**. No adjustments to the power level is made if the pair of RBs belong to the same UE and the same channel.

[0101] In block **1640**, the eNB analyzes either the channel or the UE to which both RBs of the k^{th} pair belong by determining whether the channel/UE where the RB with lower power has higher priority. If the lower power RB does not have higher priority, then the method continues to block **1645**. If the lower power RB has higher priority, then the method continues to block **1650**.

[0102] In blocks **1650**, the eNB selects to reduce the power of the higher power RB until

$$\frac{P_{i,u}}{P_{i+1,u}} = \mu \text{ or}$$

selects to transmit zero power in subcarriers that are adjacent to the lower power RB having higher priority. Next, the method continues to block **1635**.

[0103] In block **1645**, if the UE/channel to which the higher power RB has higher priority than the UE/channel to which the lower power RB belongs, then the eNB reduces the power such that the resulting modulation and coding scheme (MCS) remains unchanged for the high priority UE/channel. The eNB can select to reduce the power of the higher power RB until

$$\frac{P_{i,u}}{P_{i+1,u}} = c\mu$$

for c>1. The coefficient c denotes a multiplier by which overhead is reducible without compromising performance of the higher priority channel or higher priority UE. Next, the method continues to block **1635**.

[0104] In block **1655**, after the eNB has incremented the counter index (u) for the UEs, the eNB determines whether the current UE (i.e., u_{th} UE) is the last UE of the total number (U) of UEs within the cell of eNB **301**. If the u_{th} UE is last (i.e., u=U), then the method moves to block **1660**. If the u_{th} UE is not last (i.e., u<U), then the method moves to block **1605**.

[0105] In block **1660**, eNB scales up the power of the entire subframe. The eNB recalculates the MCS for all of the UES under the adjusted power allocation.

[0106] FIG. **17** illustrates an example of power control for different channels considering ICI according to embodiments of the present disclosure. The embodiment of the power control shown in FIG. **17** is for illustration only. Other embodiments could be used without departing from the scope of the present disclosure.

[0107] In cases of more than one UE scheduled in the high power RB, there will be multiple ways of reduce the total transmit power of this RB. For example, eNB can select to only reduce the power of the UE having precoders that cause the highest receive power.

[0108] The graph **1700** shows that the un-beamformed PBCH **1710*a*** (shown by dark shading) and the beamformed PDSCH **1710*a***, **1720*a***, **1730*a***, **1740*a*** collectively (shown by light shading) are transmitted to the same UE.

[0109] The graph **1702** shows that eNB analyzes the received power distribution and determines that the power dynamic range between the first pair of RBs (RB_0 and RB_1) is 15 dB, which is the same for the second pair of RBs (RB_6 and RB_7). That is, the received power of the beamformed PBCH **1715*a***, **1725*a***, **1735*a***, **1745*a*** is 15 dB greater than the received power of the broad beamwidth-low beamforming gain PBCH **1705*a***. By comparing the power dynamic range to a threshold value μ=12 dB, the eNB determines that the transmit power of RB_0 and RB_7 should be reduced to mitigate ICI to the broad beamwidth-low beamforming gain PBCH **1705*a***.

[0110] The graph **1703** shows that the eNB reduces the transmit power in the RBs **1710*b*** and **1720*b*** (RB_0 and RB_7) adjacent to the center PBCH channel **1700*b*** (RB_1-RB_6) by a certain dB (e.g., 3 dB). This will not impact the UE demodulation for the PDSCH, as the channel estimation is performed via the DM-RS within a RB having power that is also reduced.

[0111] In this case, the graph **1704** shows that the SNR of the REs in the PBCH **1705*b*** can be approximately improved by 3 dB.

[0112] FIG. **18** illustrates an example of power control for different UEs considering ICI according to embodiments of the present disclosure. The embodiment of the power control shown in FIG. **18** is for illustration only. Other embodiments could be used without departing from the scope of the present disclosure.

[0113] The graph **1801** shows that the eNB schedules UE_1 and UE_2 in adjacent RBs where UE_1's PDSCH is beamformed with high beamforming gain while UE_2's PDSCH is not beamformed (e.g., or beamformed with low beamforming gain). In addition, the eNB determines that UE_1 and UE_2 are in a similar direction (thus similar channel directions) based on the PMI feedback or SRS channel estimation. Accordingly, the precoders/beamformers used for UE_1 will also beamform to UE_2 as well. In case of ideal frequency synchronization there will be no issue, as UE_1 and UE_2 are orthogonal in frequency. The graph **1802** shows that the frequency error may cause the interference to leak from the RBs assigned for UE_1 to UE_2, where the receive power in UE_1 is much larger than the receive power in UE_2 (a similar situation discussed in reference to graph **1702** of FIG. **17**). As the received power for the UE_3 is 10 dB greater than the received power for UE_2, which is less than the threshold value μ=12 dB, the UE**2** can correctly decode its signals despite mild interference from UE_3.

[0114] The graph **1803** shows that the eNB can reduce the adjacent RB of UE_1 to UE_2 by a certain e.g. 3 dB. The graph **1804** shows that as a result of the 3 dB transmit power reduction at UE_1, the power dynamic range between UE_1 and UE_2 changes from an intolerable 15 dB to a tolerable 12 dB. That is, from UE_2's perspective, the receive power attributable to the UE_1 for is tolerable.

[0115] From a system perspective, the eNB select to switch between the RB power reduction described here and the RE guarding method described above, assuming the standard supports the signaling of RE guard pattern. The eNB calculates the effective rate.

[0116] FIG. **19** illustrates an example of an RE blanking implementation according to embodiments of the present disclosure. The embodiment of the RE blanking shown in FIG. **19** is for illustration only. Other embodiments could be used without departing from the scope of the present disclosure.

[0117] In the RE blanking implementation, eNB nulls the subcarriers of a high power RB that are adjacent to a low power RB. After the RE muting, the eNB selects whether or not to adjust the MCS level of the TB index of the high power UE, because it is realistic to assume the presence of at least some redundancy in the transmission.

[0118] In graph **1901**, the eNB receives UEs' feedback report on CQI and PMI (in FDD) or estimating uplink channels based on SRS sounding signals (in TDD). The eNB calculates MCS level based on PMI (or SRS channel estimation), CQI and power allocation for UEs. The eNB estimates the receive power for all RBs from the UE's perspective. The power is denoted as P_i, where i=1, . . . , N and N is the total number of RBs in use.

[0119] In graph **1902**, the eNB identifies all pairs of consecutive 2 RBs, where

$$\frac{P_i}{P_{i+1}} > \mu \text{ or } \frac{P_{i+1}}{P_i} > \mu.$$

As shown, although the maximum tolerable dynamic power range is set to a threshold value μ=12 dB, the received power for UE_1 is 15 dB greater than the received power for UE_2. The received power for the UE_3 is 10 dB greater than the received power for UE_2, which corresponds to a tolerable amount of interference smaller than the threshold value μ.

[0120] Graph **1903** shows that if the UE/channel (UE_1) to which the higher power RB belongs has lower priority than the UE/channel (UE_2) to which the lower power RB belongs, then eNB nulls subcarriers **1910** in the higher power RB that are adjacent to the lower power RB (UE_2). The eNB scales up the power of the entire subframe. The eNB recalculates the MCS for all the UEs.

[0121] The graph **1904** shows that the subcarriers of higher priority UE_1 that are adjacent to the lower priority UE_2 are muted to a zero receive power level, while the remaining subcarriers of the higher priority UE_1 are received at a power level that exceeds the threshold value μ=12 dB. That is, the non-adjacent subcarriers of higher priority UE_1 produce a dynamic power range of 15 dB between UE_1 and UE_2.

[0122] 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 method comprising:

identifying at least one pair of adjacent resource blocks within a same subframe, the at least one pair including a low power resource block (RB) and a high power RB, wherein the low power RB has a substantially lower beamforming gain compared to the high beamforming gain of the high power RB such that a ratio (R) comparing receive powers of the high power RB and the low power RB to each other is greater than a threshold ratio (μ); and

reducing a transmit power of the high power RB to a reduced transmit power level at which the ratio R is less than or equal to the threshold ratio μ (R≤μ), and

transmitting zero power at REs of the high power RB that are adjacent to the low power RB.

2. The method of claim **1**, wherein reducing the transmit power of the high power RB to the reduced transmit power level further comprises:

in response to determining that the high power RB belongs to a first user equipment (UE_1) and that the low power RB belongs to a second user equipment (UE_2), reducing the transmit power of the UE_1's high power RB to the reduced transmit power level.

3. The method of claim **1**, wherein reducing the transmit power of the high power RB to the reduced transmit power level further comprises:

in response to determining that the high power RB belongs to a first channel and that the low power RB belongs to a second channel, reducing the transmit power of the first channel's high power RB to the reduced transmit power level.

4. The method of claim **1**, wherein reducing the transmit power of the high power RB to a reduced transmit power level further comprises:

muting REs in the high power RB that are adjacent to the low power RB to zero power.

5. The method of claim **1**, wherein reducing the transmit power of the high power RB to the reduced transmit power level further comprises:

in response to determining that the low power RB has a higher priority than the high power RB, reducing the transmit power of the high power RB to the reduced transmit power level.

6. The method of claim **1**, wherein the reduced transmit power level is determined by one of two equations:

$$R = \frac{P_i}{P_{i+1}} \text{ and } R = \frac{P_{i+1}}{P_i},$$

where P_i represents an estimate of receive power of an i^{th} RB, where P_{i+1} represents an estimate of receive power of an adjacent $(i+1)^{th}$ and where i represents an index counter for all RBs of a subframe.

7. A base station comprising:

processing circuitry configured to:

identify at least one pair of adjacent resource blocks within a same subframe, the at least one pair including a low power resource block (RB) and a high power RB, wherein the low power RB has a substantially lower estimate of receive power compared to the high power RB such that a ratio (R) comparing receive powers of the high power RB and the low power RB to each other is greater than a threshold ratio (μ), and

reduce a transmit power of the high power RB to a reduced transmit power level at which the ratio R is less than or equal to the threshold ratio μ (R≤μ), and

control a transmitter to transmit zero power at REs of the high power RB that are adjacent to the low power RB; and

the transmitter configured to transmit a signal using the reduced transmit power level.

8. The base station of claim **7**, wherein the processing circuitry is further configured to:

in response to determining that the high power RB belongs to a first user equipment (UE_1) and that the low power RB belongs to a second user equipment (UE_2), reduce the transmit power of the UE_1's high power RB to the reduced transmit power level.

9. The base station of claim **1**, wherein the processing circuitry is further configured to:

in response to determining that the high power RB belongs to a first channel and that the low power RB belongs to a second channel, reducing the transmit power of the first channel's high power RB to the reduced transmit power level

10. The base station of claim **7**, wherein the processing circuitry is further configured to:

in response to determining that the low power RB has a higher priority than the high power RB, reducing the transmit power of the high power RB to the reduced transmit power level.

11. The base station of claim **7**, wherein the processing circuitry is further configured to reduce the transmit power of the high power RB to a reduced transmit power level by muting resource elements in the high power RB that are adjacent to the low power RB to zero power.

12. The base station of claim **7**, wherein the reduced transmit power level is determined by one of two equations:

$$R = \frac{P_i}{P_{i+1}} \text{ and } R = \frac{P_{i+1}}{P_i},$$

where P_i represents a transmit power of an i^{th} RB, where P_{i+1} represents a transmit power of an adjacent $(i+1)^{th}$ RB, and where i represents an index counter for all RBs of a subframe.

13. The base station of claim **7**, wherein the high power RB is a precoded RB and the low power RB is an unprecoded RB.

14. A method comprising:

identifying at least a first subframe (k), wherein each identified subframe includes a first resource block (RB) having high beamforming gain;

configuring an user equipment (UE) whether to expect a resource element guarding pattern to be ON or OFF in each RB in the first subframe.

15. The method of claim **14**, further comprising configuring the UE whether to expect a resource guarding pattern in each RB in a second subframe (k+1) next following the first subframe;

configuring the advanced user UE to expect a resource guarding pattern to be ON in the RB of the first subframe;

configuring the advanced user UE to expect a resource guarding pattern to be OFF the RB of the in the second subframe.

16. The method of claim **14**, wherein configuring the advanced UE whether to expect resource element guarding pattern in a channel comprises:

an implicit configuration by transmission scheme, wherein the advanced UE assumes an RE guarding pattern based on a scheduled transmission scheme;

an implicit configuration by transmission mode, wherein the advanced UE assumes an RE guarding pattern based on a configured transmission mode.

17. The method of claim **14**, wherein configuring the advanced UE whether to expect resource element guarding pattern in a channel comprises one of:

transmitting one bit of information to indicate whether an RE guarding pattern is ON or OFF; and

transmitting at least two-bits of information to the advanced UE indicating whether an RE guarding pattern is OFF and if ON, further indicating a selected RE guarding pattern, selected from a plurality of RE guarding patterns.

18. The method of claim **17**, wherein the plurality of RE guarding patterns include three different guarding patterns, including:

a CRS port 1 RE guarding pattern,

a CRS port 2 RE guarding pattern, and

a CSI-RS port 1 RE guarding pattern.

19. The method of claim **14**, wherein configuring an advanced user equipment (UE) whether to expect resource element guarding pattern in a channel comprises:

using higher layer signal including a radio resource control (RRC) protocol layer.

20. The method of claim **14**, further comprising transmitting a power reduction indicator to the advanced UE indicating a power ratio of the first RB, the power ratio being a transmit power of guard resources element (REs) compared to a transmit power of other Physical Downlink Shared Channel (PDSCH) REs within the first RB.

21. The method of claim **20**, wherein the power ratio is infinitely negative (−∞) yielding muted guard REs having a zero value transmit power.

22. The method of claim **20**, wherein the power reduction indicator includes at least two-bits of state information, and wherein the two-bits indicate a selected power ratio according to the table below:

State of the 2-bit field	Power ratio
00	0
01	−3
10	−6
11	−9

23. The method of claim **20**, wherein the power reduction indicator includes at least two-bits of state information, and wherein the two-bits indicate a selected power ratio according to the table below:

State of the 2-bit field	Power ratio
00	−3
01	−6
10	−9
11	−∞

24. The method of claim **14**, wherein configuring the advanced UE whether to expect resource element guarding pattern in a channel comprises transmitting at least two-bits of state information, the at least two-bits including at least one bit indicating a selected RE guarding pattern and at least another bit indicating a power ratio of the first RB.

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