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(54) **COORDINATED INTERFERENCE MITIGATION AND CANCELATION**

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(58) **Field of Classification Search**
None
See application file for complete search history.

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(57) **ABSTRACT**

A method includes receiving at user equipment an indication of a subset of scheduling constraints for interference mitigation and cancelation and performing interference mitigation and cancelation utilizing the subset of scheduling constraints.

16 Claims, 7 Drawing Sheets

400

INDEX (410)	RB ALLOCATION (415)	MODULATION ORDER (420)	TM (425)	RS PORT POSITIONS (430)	#CO-SCHEDULED UEs (435)	#CO-SCHEDULED RANKS (440)
0	UE DOES NOT CHANGE IN MIDDLE	SAME AS UE0	SAME AS UE0	SAME AS UE0	1	1
1	UE DOES NOT CHANGE IN MIDDLE	SAME AS UE0	SAME AS UE0	SAME AS UE0	2	2
2	UE SWITCHES ONCE IN THE MID-POINT	$M(0)-1 \leq M(k) \leq M(0)+1$	SAME AS UE0	SAME AS UE0	2	4
3	UE SWITCHES ONCE IN THE MID-POINT	$M(0)-1 \leq M(k) \leq M(0)+1$	SAME AS UE0	SAME AS UE0	<=4	<=4

(51) **Int. Cl.**
H04W 8/00 (2009.01)
H04W 88/02 (2009.01)

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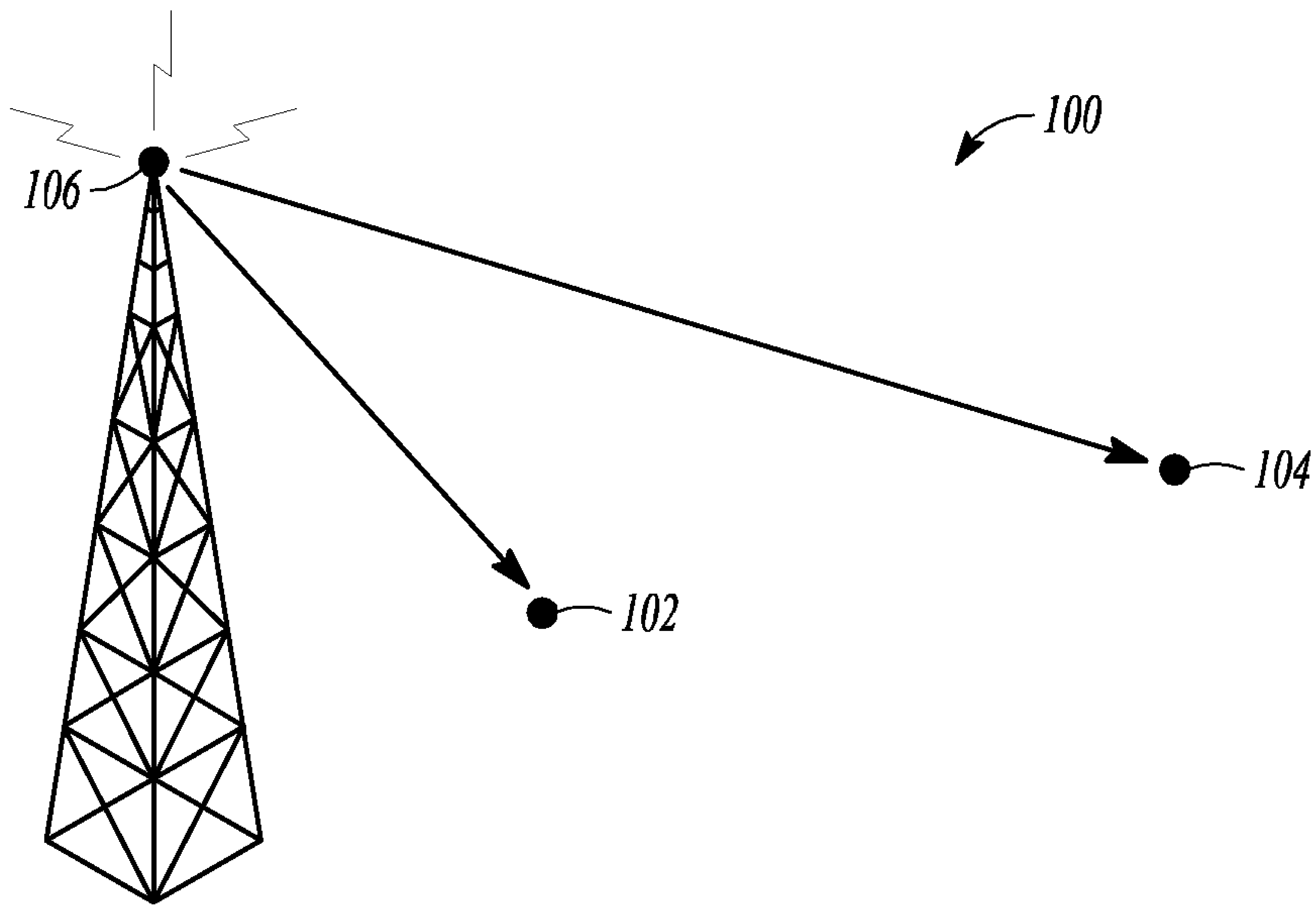

FIG. 1A

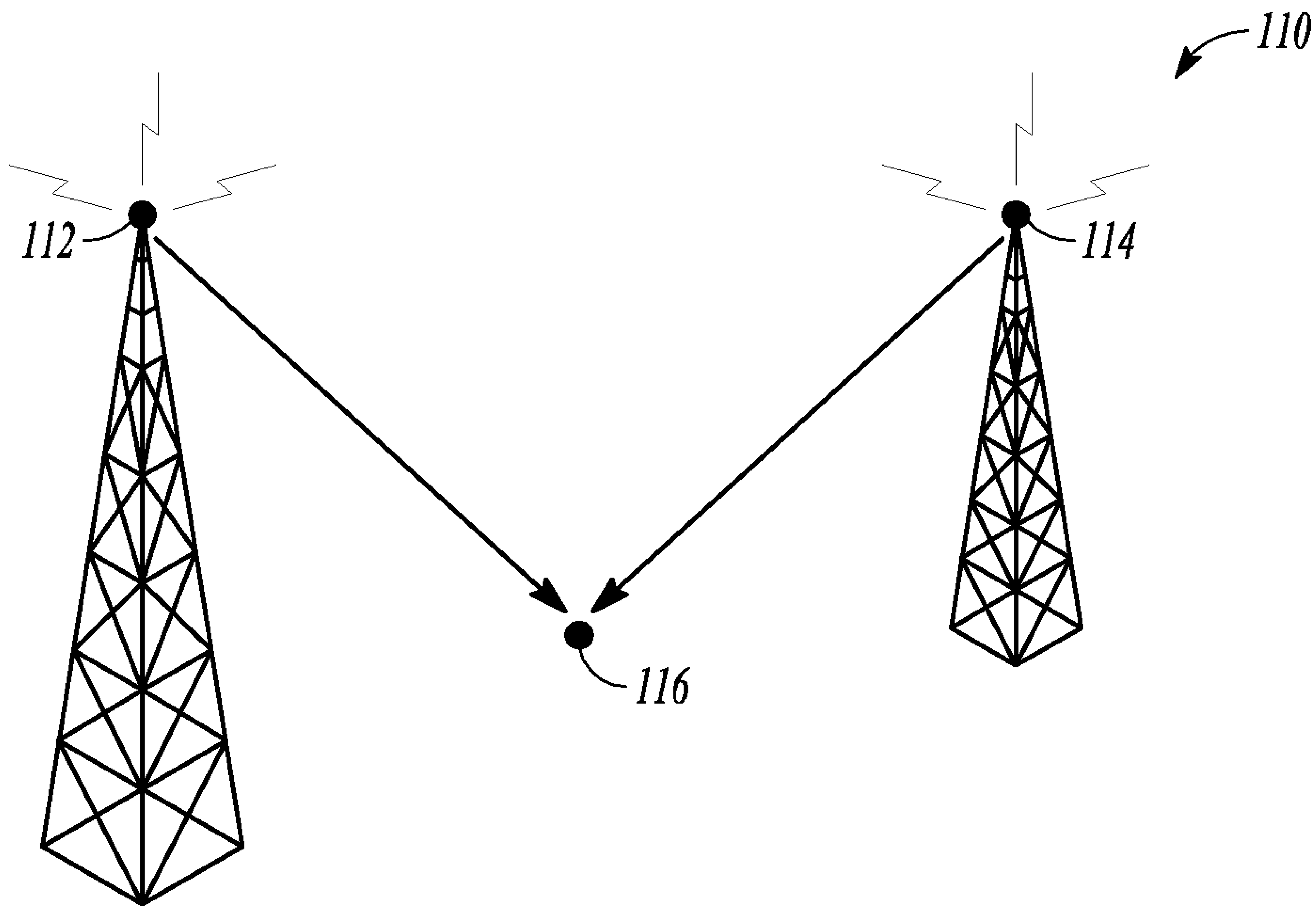

FIG. 1B

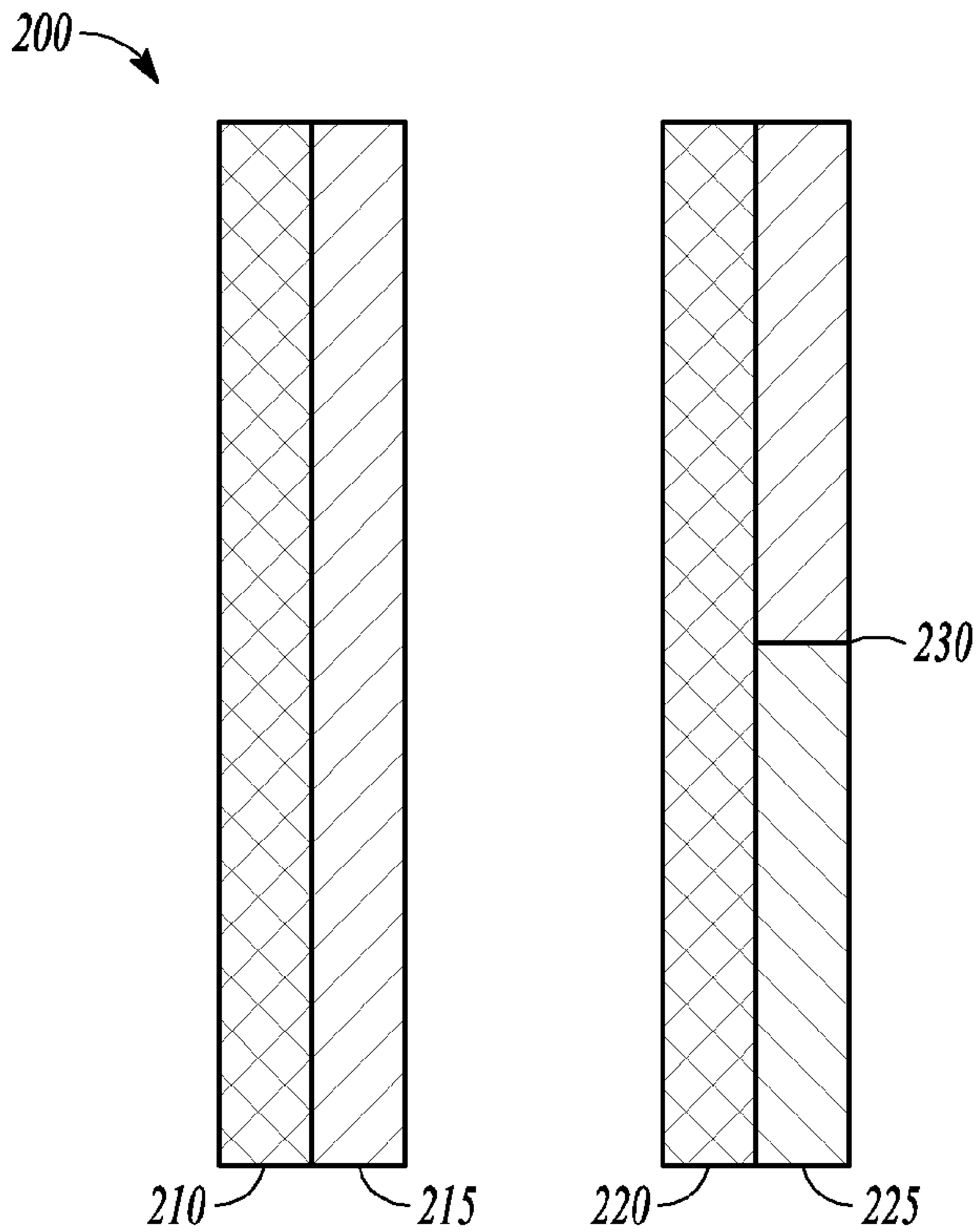
200
230
210
215
220
225

FIG. 2

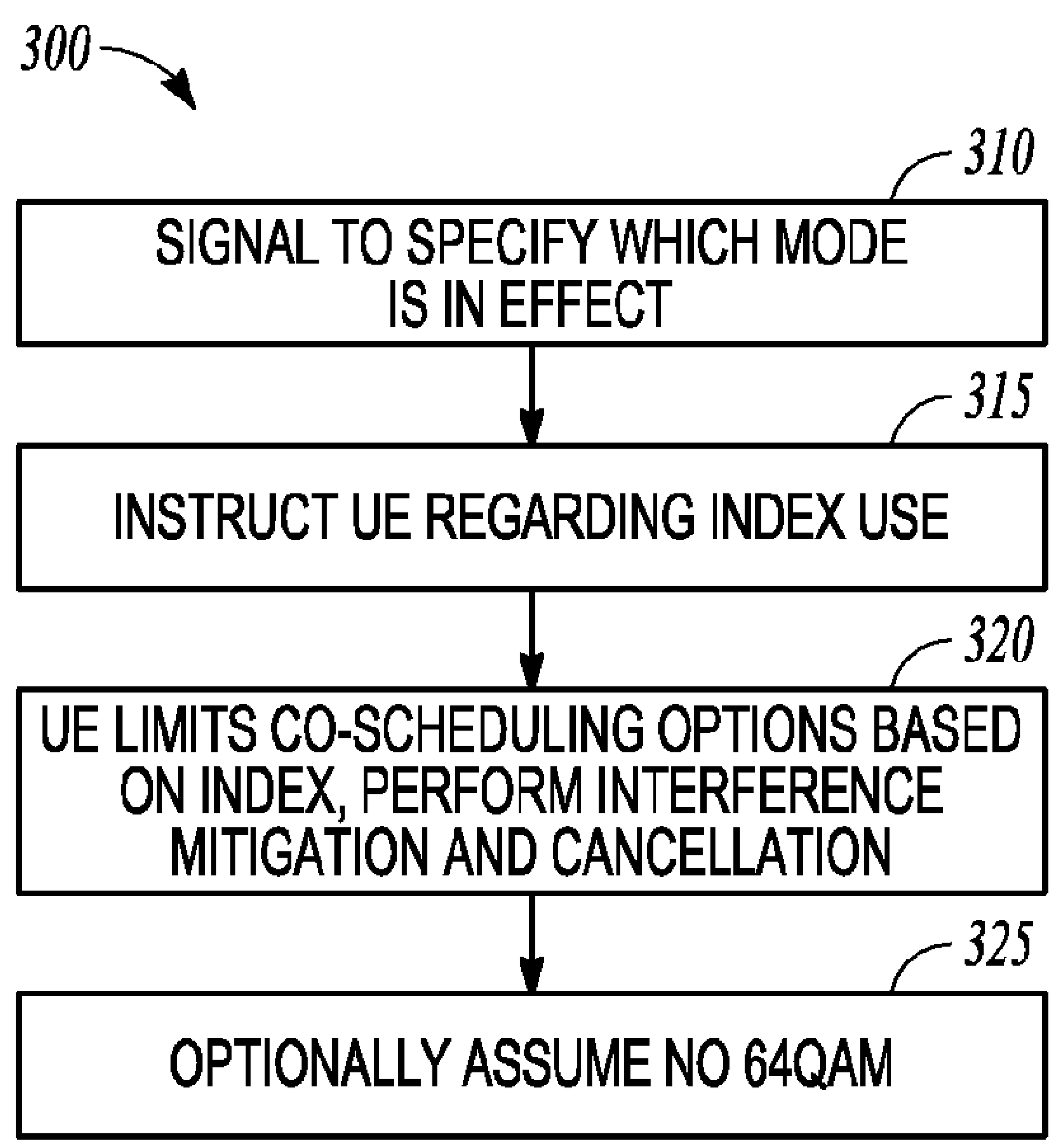
300
310
SIGNAL TO SPECIFY WHICH MODE IS IN EFFECT
315
INSTRUCT UE REGARDING INDEX USE
320
UE LIMITS CO-SCHEDULING OPTIONS BASED ON INDEX, PERFORM INTERFERENCE MITIGATION AND CANCELLATION
325
OPTIONALLY ASSUME NO 64QAM

FIG. 3

400

INDEX (410)	RB ALLOCATION (415)	MODULATION ORDER (420)	TM (425)	RS PORT POSITIONS (430)	#CO-SCHEDULED UEs (435)	#CO-SCHEDULED RANKS (440)
0	UE DOES NOT CHANGE IN MIDDLE	SAME AS UE0	SAME AS UE0	SAME AS UE0	1	1
1	UE DOES NOT CHANGE IN MIDDLE	SAME AS UE0	SAME AS UE0	SAME AS UE0	2	2
2	UE SWITCHES ONCE IN THE MID-POINT	$M(0)-1 \leq M(k) \leq M(0)+1$	SAME AS UE0	SAME AS UE0	2	4
3	UE SWITCHES ONCE IN THE MID-POINT	$M(0)-1 \leq M(k) \leq M(0)+1$	SAME AS UE0	SAME AS UE0	<=4	<=4

FIG. 4

500

410 415 420 425 430 435 510

INDEX	RB ALLOCATION	MODULATION ORDER	TM	RS PORT POSITIONS	#CO-SCHEDULED UEs	#CO-SCHEDULED RANKS
0	UE DOES NOT CHANGE IN MIDDLE	SAME AS UE0	SAME AS UE0	SAME AS UE0	1	NO INDICATION
1	UE DOES NOT CHANGE IN MIDDLE	SAME AS UE0	SAME AS UE0	SAME AS UE0	2	POWER DIFF SX dB
2	UE SWITCHES ONCE IN THE MID-POINT	$M(0)-1 \leq M(k) \leq M(0)+1$	SAME AS UE0	SAME AS UE0	2	POWER DIFF SX dB
3	UE SWITCHES ONCE IN THE MID-POINT	$M(0)-1 \leq M(k) \leq M(0)+1$	SAME AS UE0	SAME AS UE0	<=4	POWER DIFF SX dB

FIG. 5

600

INDEX (610)	RB ALLOCATION (615)	MODULATION ORDER (620)	TM (625)	RS PORT POSITIONS (630)	#CO-SCHEDULED UEs (635)	#CO-SCHEDULED RANKS (640)
0	UE DOES NOT CHANGE IN MIDDLE	SAME AS UE0	SAME AS UE0 OR LEGACY	SAME AS UE0	1	1
1	UE DOES NOT CHANGE IN MIDDLE	SAME AS UE0 (ALL LAYERS)	SAME AS UE0 OR LEGACY (ALL LAYERS)	SAME AS UE0 (ALL LAYERS)	1	2
2	UE DOES NOT CHANGE IN MIDDLE	SAME AS UE0	SAME AS UE0	SAME AS UE0	2	2
3	UE DOES NOT CHANGE IN MIDDLE	$M(0)-1 \leq M(k) \leq M(0)+1$	SAME AS UE0	SAME AS UE0	2	4
4	UE SWITCHES ONCE IN THE MID-POINT	$M(k) = M(0)-1$, OR $M(0)$	SAME AS UE0	SAME AS UE0	2	4
5	UE SWITCHES ONCE IN THE MID-POINT	$M(k) = M(0)+1$	SAME AS UE0	SAME AS UE0	2	4
6	UE SWITCHES ONCE IN THE MID-POINT	$M(k) = M(0)-1$, OR $M(0)$	SAME AS UE0	SAME AS UE0	<=1	<=1
7	UE SWITCHES TWICE N THE MIDDLE	$M(k) \leq M(0)+1$	SAME AS UE0	SAME AS UE0	<=4	<=4

FIG. 6

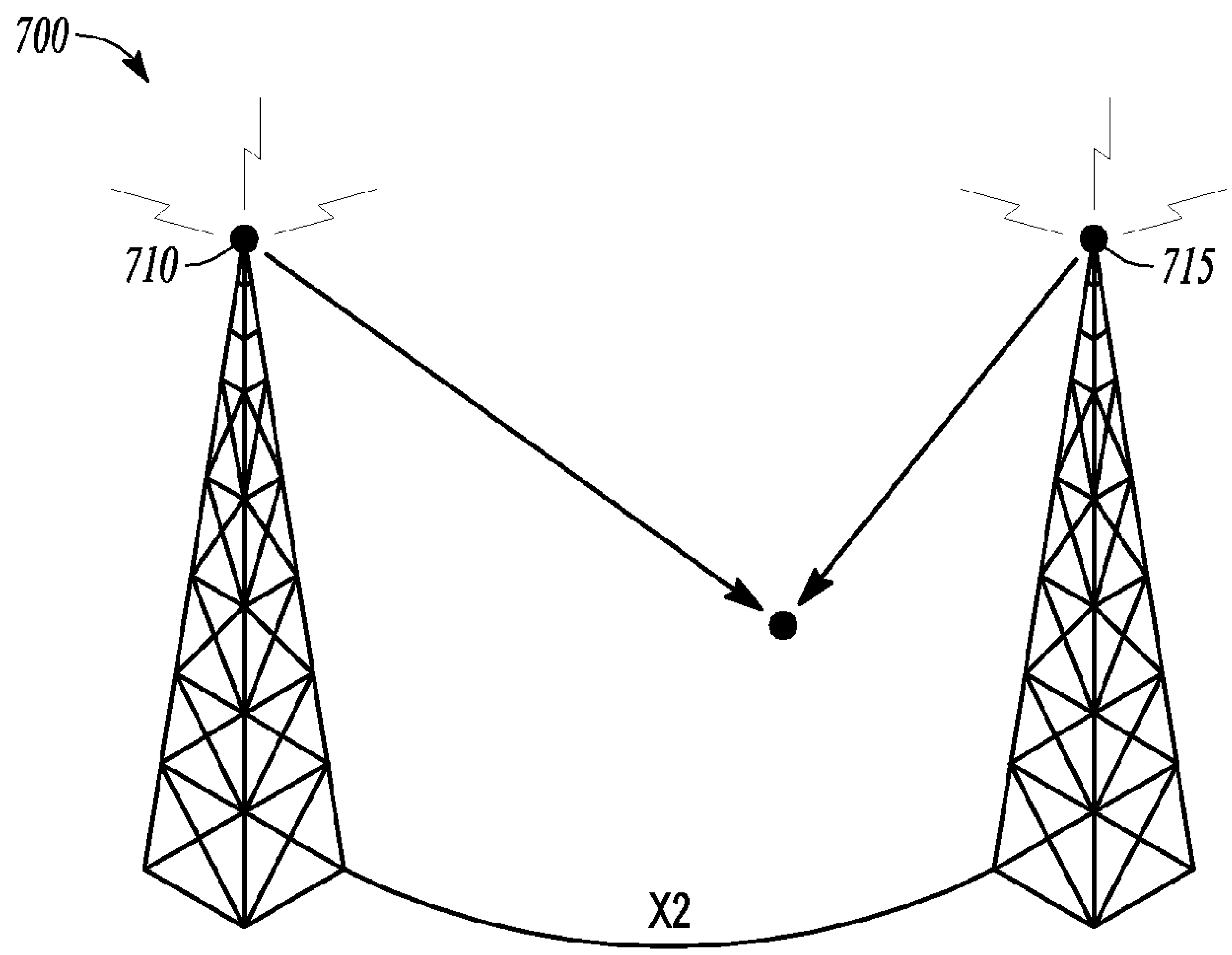

FIG. 7A

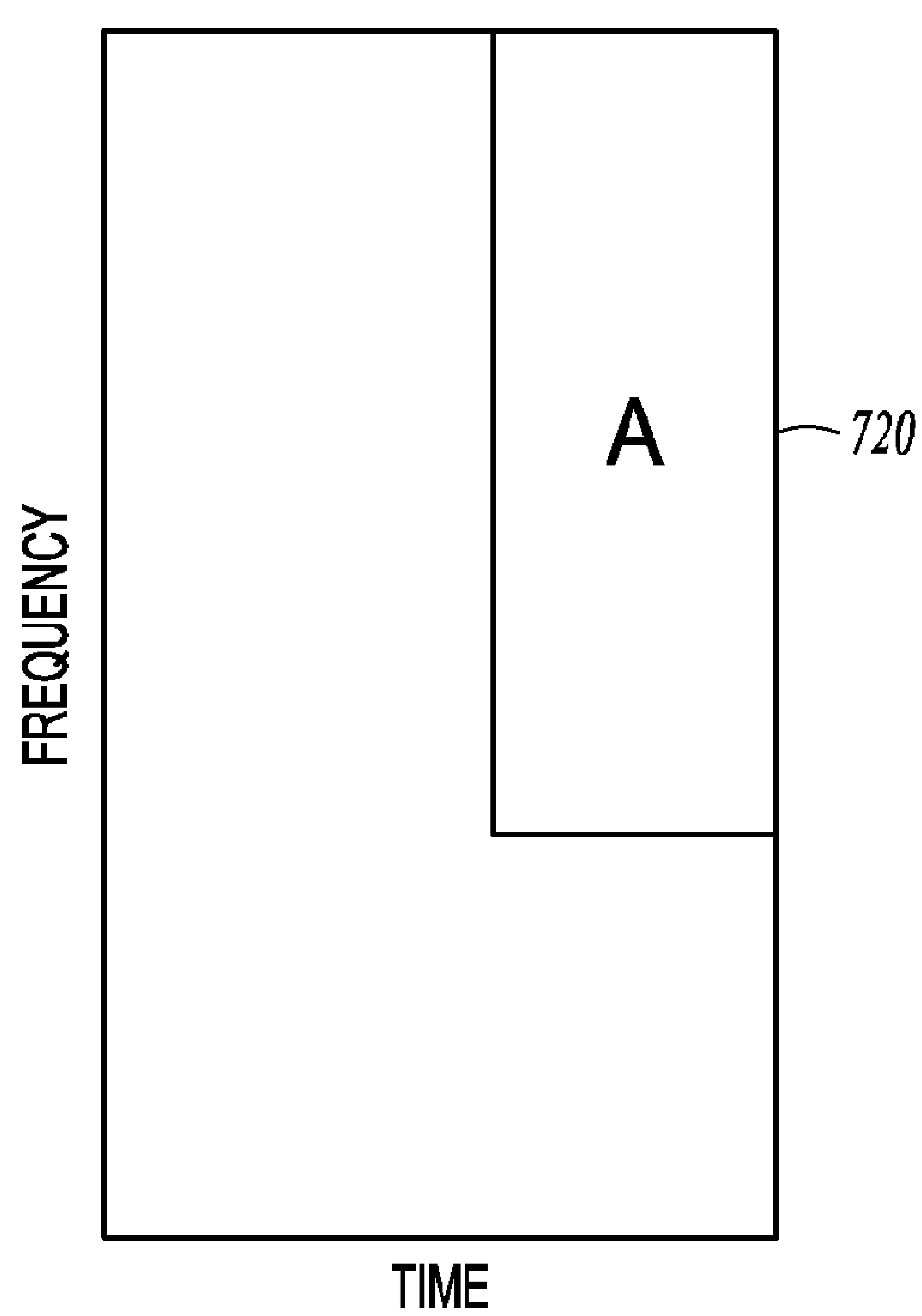

FIG. 7B

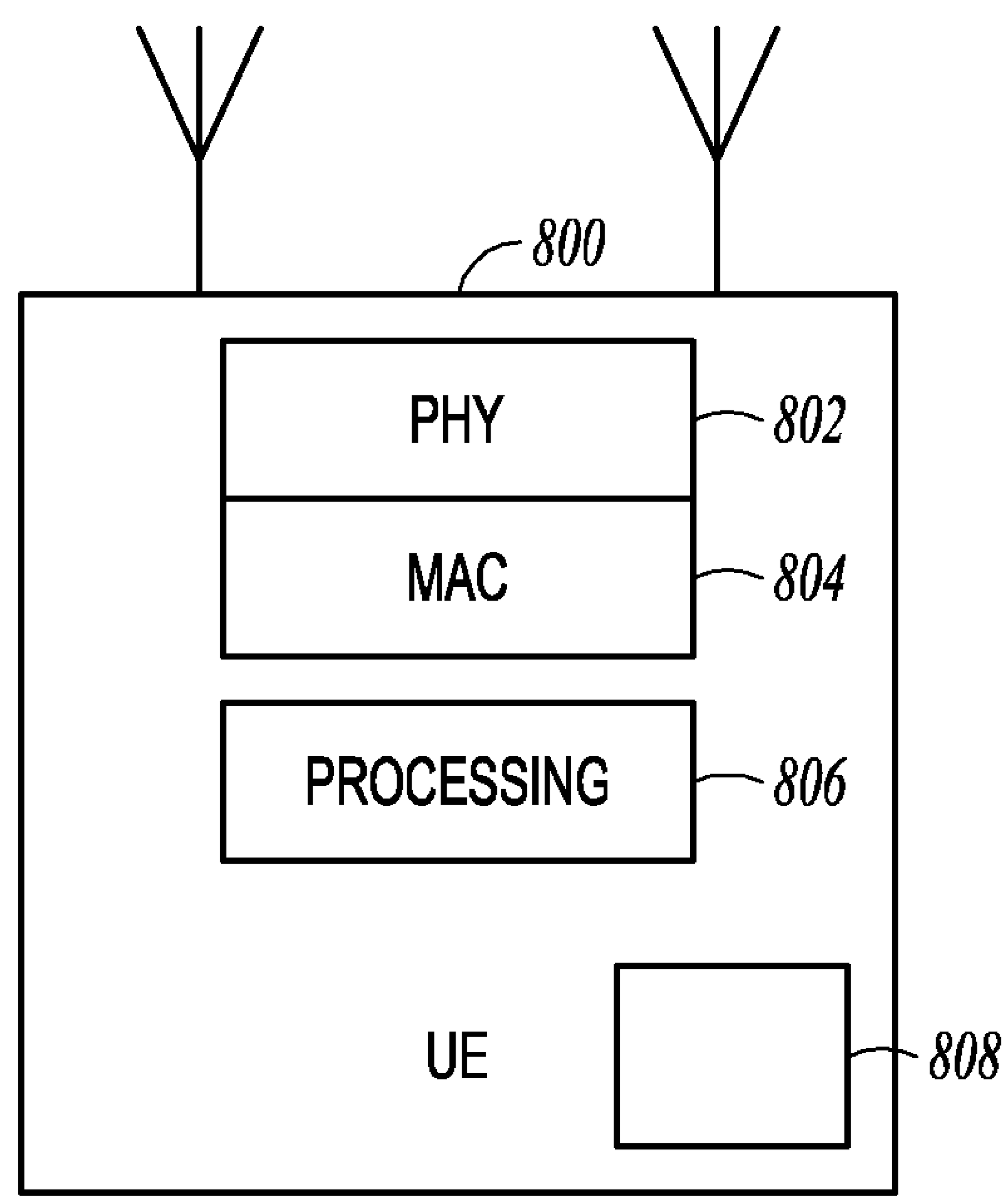

FIG. 8

COORDINATED INTERFERENCE MITIGATION AND CANCELATION

RELATED APPLICATION

This application claims priority to U.S. Provisional Application Ser. No. 61/843,826 (entitled ADVANCED WIRELESS COMMUNICATION SYSTEMS AND TECHNIQUES, filed Jul. 8, 2013) which is incorporated herein by reference in its entirety.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A is a block diagram illustrated intra-cell interference according to an example embodiment.

FIG. **1**B is a block diagram illustrating inter-cell interference according to an example embodiment.

FIG. **2** is a block diagram illustrating limitations on jointly scheduled UEs according to an example embodiment.

FIG. **3** is a flowchart illustrating a method of performing interference mitigation and cancelation according to an example embodiment.

FIG. **4** is a table of coordination combinations using a two bit index according to an example embodiment.

FIG. **5** is an alternative table of coordination combinations using a two bit index according to an example embodiment.

FIG. **6** is a table of coordination combinations using a three bit index according to an example embodiment.

FIGS. **7**A and **7**B are block diagrams illustrating inter-cell coordination according to an example embodiment.

FIG. **8** is a block diagram of an example cell station according to an example embodiment.

BACKGROUND

Interference is a serious issue in wireless cellular communications, especially as the cell size gets smaller and user equipment (UE) density gets higher. It has been shown that interference mitigation and cancelation (IMC) techniques can be implemented at the UE side for better throughput and quality of service (QoS). Since signals from intra-cell or inter-cell UEs are typically controlled and coded using private scrambling or allocations, especially in existing releases, an UE can only do blind IMC by exhaustive search or by linear processing based on statistics. This entails either high complexity or poor performance for IMC.

DETAILED DESCRIPTION

The following detailed description refers to the accompanying drawings. The same reference numbers may be used in different drawings to identify the same or similar elements. In the following description, for purposes of explanation and not limitation, specific details are set forth such as particular structures, architectures, interfaces, techniques, etc. in order to provide a thorough understanding of the various aspects of the claimed invention. However, it will be apparent to those skilled in the art having the benefit of the present disclosure that the various aspects of the invention claimed may be practiced in other examples that depart from these specific details. In certain instances, descriptions of well-known devices, circuits, and methods are omitted so as not to obscure the description of the present invention with unnecessary detail.

Interference is a serious issue in wireless cellular communications, especially as the cell size gets smaller and user equipment (UE) density gets higher. It has been shown that interference mitigation and cancelation (IMC) techniques can be implemented at the UE side for better throughput and quality of service (QoS). Since signals from intra-cell or inter-cell UEs are typically controlled and coded using private scrambling or allocations, a UE can only do blind IMC by exhaustive search or by linear processing based on statistics. This entails either high complexity or poor performance for IMC. This is because the number of possible combinations between resource allocation, PMI (precoding matrix indicator), and MCS (modulation coding scheme) etc., is a big number. By sending the UE some side information about the co-scheduled UE(s) or even cross-cell UEs, one expects to achieve better IMC result. As a result, example embodiments enable network-assisted interference cancelation and mitigation.

In various examples, intra-cell and inter-cell transmissions on the MCS/resource allocation level are coordinated. An associated side-information transmission and coding method is provided for notifying UEs, so that a more efficient and effective IMC is achieved.

In one embodiment, scheduling coordination is performed between MU-MIMO (multiple user multiple-input multiple-output) UEs in one cell and the coordination across neighboring cells. When the base station (eNB—evolved node B) schedules a pair or more UEs in a cell for MU-MIMO, the combinations among MCS, precoding (PMI—precoding matrix indicator) and frequency-time resources are limited to a smaller number of possibilities. The combinations are narrowed and indexed using a few bits, which will be sent to the UEs as a new type of DCI (downlink control indicator) for better IMC. In some example embodiments, there may be more than MCS, PMI and frequency-time resources. One example is power.

In cross-cell coordination, a slow coordination between cells is presented which determines a set of frequency-time resource so that neighboring cells can allocate interference-suffering UEs in this region. In this so-called 'Interference Coordination Region' (IC-Region), a limited number of MCS/resource scheduling/PMI etc., combinations are allowed. UEs scheduled in such region can assume that the interference signal has limited possible allocations on resource allocation and/or MCS etc. This allows better IMC and better interference situation. Several specific options in encoding are also provided.

FIGS. **1**A and **1**B illustrate two interference situations. Intra-cell interference is illustrated at **100** in FIG. **1**A, and involves interference between different UE indicated at **102** and **104** in a single base station (eNB) indicated at **106**. Inter-cell interference is illustrated at **110** in FIG. **1**B, and involves interference between two base stations **112**, **114** at one or more UEs indicated at **116**. The sizes of the arrows indicate relative signal strengths between the UEs and the cell stations. The design for intra-cell coordination can be considered a special case of the inter-cell coordination in various examples. Note that limiting combinations will gain overall in terms of system throughput especially at cell-edge UEs. This is because these UEs will not perform well with high MCS orders, fancy scheduling, or complicated combinations.

Example mechanisms provide intra-cell and inter-cell coordination without much overhead. By carefully choosing the limited number of combinations, a better trade-off is achieved between interference-cancelation performance of cell-edge UEs and overall system throughput.

In LTE, scheduling of a UE's transmission has many parameters such as modulation order (e.g. QPSK/16QAM/64QAM), MCS (index of the modulation/coding combinations), PMI, resource allocations, transmission mode, layers/

ranks etc. We call this set of parameters the 'scheduling parameters'. This creates a big search space for any UE that tries to do interference cancelation or mitigation in a fine way.

In one example, a scheduling method for the eNB limits the number of possible combinations between co-scheduled UEs (e.g. MU-MIMO or cross-cell). This may be referred to as a subset of scheduling constraints, which by definition, contains fewer constraints than are normally available for use in performing interference-cancelation mitigation. In one embodiment, the scheduling constraint is on modulation/TM (transmission mode)/MCS/PMI. The coordinated parameters may be within a limited boundary of each other (as compared to the number of possibilities if there is no such coordination).

A UE may be notified by its eNB that it is under such a co-scheduling coordination, by special signaling. A new DCI format with dedicated K bits (e.g. 2 or 3) is used by the eNB to indicate the coordination pattern, i.e. which limitations are to be enforced. This new DCI may be changed at a sub-frame level.

At a high-level, such as RRC (radio resource control), with a slower period, the mapping between the bits and the coordination patterns can be changed. Neighboring cells can be coordinated over a backhaul (e.g. X**2**) in a much slower frequency for coordinating scheduling towards a better IMC performance. Neighboring cells may agree on a special resource region (IC-region) on the resource grid (e.g. a set of RBs across certain subframes). UEs scheduled in this region may have a very limited number of possible combinations of scheduling parameters. In a further example, an eNB can provide UEs in the IC-Region more information by using a new DCI as in the intra-cell coordination case.

Regarding to the possible combinations, once a UE (say UE**0**) is notified that it is scheduled with interference-coordination, the following limitation on the jointly-scheduled UEs, as illustrated at **200** in FIG. **2**, is enforced:

1) Resource allocation of any co-scheduled UEs **210**, **215** have only a limited number of starting points and scheduling patterns. For example, one option is to assume that co-scheduled UE RBs (radio bands) can only be totally overlapping or start, or in the case of UEs **220**, **225** from the mid-point **230** of UE**0**'s RB allocation, and the RBs must be continuous;

2) Modulation orders of co-scheduled UEs are within a limited range, e.g. 0 (equal order) or 1. MCS orders can be assumed to be within a certain range, which can be inferred based on the new DCI message;

3) Transmission modes are within a limited number of combinations.

4) The number of co-scheduled layers should be limited. New DCI can specify further limits on the number. E.g. no more than 2 or 4. This also applies to the number of co-scheduled UEs.

In intra-cell design, the eNB has a set of coordination modes, say Mode**1**, . . . , ModeJ. Each mode corresponds to a table of K items, with each item being represented by an index. Each item limits the scheduling options of the joint-scheduled UEs. The coordinated properties include: RB allocation, modulation order, TM, number of co-scheduled UEs, number of layers, etc.

A method **300** of performing interference mitigation and cancelation utilizing various resource allocation modes is illustrated in FIG. **3**. At **310**, RRC signaling may be used to specify which mode is in effect. At **315**, in a control instruction (PDCCH), the coordination is instructed to the UE by letting it know the item's index. At **320**, based on the 'mode' and 'item index', the UE limits the co-scheduling options, which helps its interference mitigation in decoding. At **325**, a UE can typically assume that all its co-scheduled UEs don't use 64QAM. (Because 64QAM is the finest modulation order and like random Gaussian noise already.)

DCI may be used in two different options. In a first option, a private DCI is sent to a co-scheduled UE as identified by the eNB. This option allows a legacy UE who does not understand the new DCI to be co-scheduled. In a second option, a common DCI is multi-casted to all co-scheduled UEs. This control channel may be scrambled and coded using sequences known to all these UEs.

Several design options may utilize at least 2 or 3 bits indicating the coordination combinations. In one example, two-bit information is sent. Each such information indicates certain limitations on possible combinations. The emphasis is the case when the co-scheduled UEs have similar scheduling setup.

In one specific example illustrated in table form in FIG. **4** at **400**, it is assumed that UE**0** is the UE that received this new DCI. M(**0**) is the modulation order of UE**0**, and M(k) is for the coordinated UE(k). An index column **410** shows four entries, 0, 1, 2, and 3, corresponding to a two bit index. RB allocation is shown at **415**. The RB allocation may change in the middle or switch once at a mid-point in this example. Modulation order is shown at **420**, and may be the same, or vary between M(**0**)−1 and M(**0**)+1 as illustrated. A TM (Transmission mode) **425** is shown the same as UE**0** for each UE, as are the RS port positions at **430**. A number of co-scheduled UEs in column **435** varies between 1 and less than or equal to 4. A number of co-scheduled ranks at **440** may also vary between 1 and less than or equal to 4.

In a further option illustrated in table form at **500** in FIG. **5** a UE can assume that no 64QAM is used. Table **500** uses the same reference numbers as table **400** where the columns are the same. In addition, a power difference of ×dB is indicated at **510** and is a threshold number. Not much use of side information is made if 64QAM is utilized.

In a still further option, coordination between rank/RB/modulation/TM/#UEs is utilized as indicated at table **600** in FIG. **6**. The index **610** in this example is a three bit index having corresponding Arabic numbers 0 through 7, for a total of up to 8 entries. RB allocation is illustrated at **615**. Modulation order is shown at **620** and may be the same as UE**0**, the same as UE**0** on all layers, vary between M(**0**)−1 and M(**0**)+1, equal to M(**0**)−1 or M(**0**)+1, M(k)=M(**0**)+1, M(k)=M(**0**)−1 or M(**0**), M(k) less than or equal to M(**0**)+1 in various examples. In this example, the only difference between index 0 and index 1 is that the latter allows two co-scheduled ranks. The term "all layers" means that both layers' scheduling is subject to the same constraint. TM is indicated at **625** and may be the same as UE**0** or legacy, the same as UE**0** or legacy on all layers. PR port positions are indicated at **630** and may be the same as UE**0** or the same as UE**0** on all layers. A number of co-scheduled UEs is indicated at **635** and may vary between 1 and 4, with specific examples illustrated as 1, 2, and less than or equal to 4. Finally, the number of co-scheduled ranks at **640** may also range from 1 to 4, with specific examples illustrated as 1, 2, and less than or equal to 4.

A further option is that UE can assume that no 64QAM is used. Besides the above combinations, the following side information can be sent for better information compression. Side information 1: Total number of UEs/Ranks scheduled. Side information 2: maximum variations of certain parameters between the UEs. E.g. |ModulationOrder(i)−ModulationOrder(j)|<=1, excluding 64QAM; or |MCS(i)-MCS(j)|<=3.

Inter-cell coordination may also be performed. The basic structure and steps are illustrated in FIG. **7**A at **700** and in **7**B. Neighboring cells indicated at **710** and **715** exchange over X**2** (or other backhaul channel) for coordinating IMC. Over X**2**, a dedicated resource region A at **720** (freq+time) is designated as 'interference-cooperation region'(IC-region). In this IC-region **720**, each cell's scheduling can be implicitly or easily derivable by neighbors. Over a fixed period, e.g. 200 ms, the neighboring cells **710**, **715** synchronize again on IC-region A **720** and the derivation mechanism (i.e. the scheduling constraints) for scheduling in A.

Scheduling alignment in IC-region **720**: For a UE that gets scheduled in the IC-region, it can infer that the scheduling coordination takes effect. Parameters under coordination are similar as in the intra-cell MU-MIMO case.

There are many options of limiting the possible coordination combinations within IC-region. Several options are presented here, including all the UEs in region A can only use QPSK (phase-shift keying). In a further option, a UE's RB allocation starts from a specified set of RBs (e.g. continuous) and/or with fixed length (e.g 3/6/9RBs). This helps the neighbor UEs in blind interference cancelation and mitigation. In yet a further option, for each RB block, its transmission is fixed to be say RANK1, 16QAM, a very limited number of combinations.

FIG. **8** is a block diagram of a specifically programmed computer system to act as one or more different types of cell stations, including user equipment, small cell stations and macro stations. The system may be used to implement one or more methods according to the examples described. In the embodiment shown in FIG. **8**, a hardware and operating environment is provided to enable the computer system to execute one or more methods and functions that are described herein. In some embodiments, the system may be a small cell station, macro cell station, smart phone, tablet, or other networked device that can provide access and wireless networking capabilities to one or more devices. Such devices need not have all the components included in FIG. **8**.

FIG. **8** illustrates a functional block diagram of a cell station **800** in accordance with some embodiments. Cell station **800** may be suitable for use as a small cell station, macro cell station, or user equipment, such as a wireless cell phone, tablet or other computer. The cell station **800** may include physical layer circuitry **802** for transmitting and receiving signals to and from eNBs using one or more antennas **801**. Cell station **800** may also include processing circuitry **804** that may include, among other things a channel estimator. Cell station **800** may also include memory **806**. The processing circuitry may be configured to determine several different feedback values discussed below for transmission to the eNB. The processing circuitry may also include a media access control (MAC) layer.

In some embodiments, the cell station **800** may include one or more of a keyboard, a display, a non-volatile memory port, multiple antennas, a graphics processor, an application processor, speakers, and other mobile device elements. The display may be an LCD screen including a touch screen.

The one or more antennas **801** utilized by the cell station **800** may comprise one or more directional or omnidirectional antennas, including, for example, dipole antennas, monopole antennas, patch antennas, loop antennas, microstrip antennas or other types of antennas suitable for transmission of RF signals. In some embodiments, instead of two or more antennas, a single antenna with multiple apertures may be used. In these embodiments, each aperture may be considered a separate antenna. In some multiple-input multiple-output (MIMO) embodiments, the antennas may be effectively separated to take advantage of spatial diversity and the different channel characteristics that may result between each of antennas and the antennas of a transmitting station. In some MIMO embodiments, the antennas may be separated by up to 1/10 of a wavelength or more.

Although the cell station **800** is illustrated as having several separate functional elements, one or more of the functional elements may be combined and may be implemented by combinations of software-configured elements, such as processing elements including digital signal processors (DSPs), and/or other hardware elements. For example, some elements may comprise one or more microprocessors, DSPs, application specific integrated circuits (ASICs), radio-frequency integrated circuits (RFICs) and combinations of various hardware and logic circuitry for performing at least the functions described herein. In some embodiments, the functional elements may refer to one or more processes operating on one or more processing elements.

Embodiments may be implemented in one or a combination of hardware, firmware and software. Embodiments may also be implemented as instructions stored on a computer-readable storage medium, which may be read and executed by at least one processor to perform the operations described herein. A computer-readable storage medium may include any non-transitory mechanism for storing information in a form readable by a machine (e.g., a computer). For example, a computer-readable storage medium may include read-only memory (ROM), random-access memory (RAM), magnetic disk storage media, optical storage media, flash-memory devices, and other storage devices and media. In these embodiments, one or more processors of the cell station **800** may be configured with the instructions to perform the operations described herein.

In some embodiments, the cell station **800** may be configured to receive OFDM communication signals over a multicarrier communication channel in accordance with an OFDMA communication technique. The OFDM signals may comprise a plurality of orthogonal subcarriers. In some broadband multicarrier embodiments, evolved node Bs (NBs) may be part of a broadband wireless access (BWA) network communication network, such as a Worldwide Interoperability for Microwave Access (WiMAX) communication network or a 3rd Generation Partnership Project (3GPP) Universal Terrestrial Radio Access Network (UTRAN) Long-Term-Evolution (LTE) or a Long-Term-Evolution (LTE) communication network, although the scope of the invention is not limited in this respect. In these broadband multicarrier embodiments, the cell station **800** and the eNBs may be configured to communicate in accordance with an orthogonal frequency division multiple access (OFDMA) technique. The UTRAN LTE standards include the 3rd Generation Partnership Project (3GPP) standards for UTRAN-LTE, release 8, March 2008, and release 10, December 2010, including variations and evolutions thereof.

In some LTE embodiments, the basic unit of the wireless resource is the Physical Resource Block (PRB). The PRB may comprise 12 sub-carriers in the frequency domain×0.5 ms in the time domain. The PRBs may be allocated in pairs (in the time domain). In these embodiments, the PRB may comprise a plurality of resource elements (REs). A RE may comprise one sub-carrier×one symbol.

Two types of reference signals may be transmitted by an eNB including demodulation reference signals (DM-RS), channel state information reference signals (CIS-RS) and/or a common reference signal (CRS). The DM-RS may be used by the UE for data demodulation. The reference signals may be transmitted in predetermined PRBs. In some embodiments, the OFDMA technique may be either a frequency domain duplexing (FDD) technique that uses different uplink and downlink spectrum or a time-domain duplexing (TDD) technique that uses the same spectrum for uplink and downlink.

In some other embodiments, the cell station **800** and the eNBs may be configured to communicate signals that were transmitted using one or more other modulation techniques such as spread spectrum modulation (e.g., direct sequence code division multiple access (DS-CDMA) and/or frequency hopping code division multiple access (FH-CDMA)), time-division multiplexing (TDM) modulation, and/or frequency-division multiplexing (FDM) modulation, although the scope of the embodiments is not limited in this respect.

In some embodiments, the cell station **800** may be part of a portable wireless communication device, such as a personal digital assistant (PDA), a laptop or portable computer with wireless communication capability, a web tablet, a wireless telephone, a wireless headset, a pager, an instant messaging device, a digital camera, an access point, a television, a medical device (e.g., a heart rate monitor, a blood pressure monitor, etc.), or other device that may receive and/or transmit information wirelessly.

In some LTE embodiments, the cell station **800** may calculate several different feedback values which may be used to perform channel adaption for closed-loop spatial multiplexing transmission mode. These feedback values may include a channel-quality indicator (CQI), a rank indicator (RI) and a precoding matrix indicator (PMI). By the CQI, the transmitter selects one of several modulation alphabets and code rate combinations. The RI informs the transmitter about the number of useful transmission layers for the current MIMO channel, and the PMI indicates the codebook index of the precoding matrix (depending on the number of transmit antennas) that is applied at the transmitter. The code rate used by the eNB may be based on the CQI. The PMI may be a vector that is calculated by the cell station and reported to the eNB. In some embodiments, the cell station may transmit a physical uplink control channel (PUCCH) of format 2, 2a or 2b containing the CQI/PMI or RI.

In these embodiments, the CQI may be an indication of the downlink mobile radio channel quality as experienced by the cell station **800**. The CQI allows the cell station **800** to propose to an eNB an optimum modulation scheme and coding rate to use for a given radio link quality so that the resulting transport block error rate would not exceed a certain value, such as 10%. In some embodiments, the cell station may report a wideband CQI value which refers to the channel quality of the system bandwidth. The cell station may also report a sub-band CQI value per sub-band of a certain number of resource blocks which may be configured by higher layers. The full set of sub-bands may cover the system bandwidth. In case of spatial multiplexing, a CQI per code word may be reported.

In some embodiments, the PMI may indicate an optimum precoding matrix to be used by the eNB for a given radio condition. The PMI value refers to the codebook table. The network configures the number of resource blocks that are represented by a PMI report. In some embodiments, to cover the system bandwidth, multiple PMI reports may be provided. PMI reports may also be provided for closed loop spatial multiplexing, multi-user MIMO and closed-loop rank 1 precoding MIMO modes.

In some cooperating multipoint (CoMP) embodiments, the network may be configured for joint transmissions to a cell station in which two or more cooperating/coordinating points, such as remote-radio heads (RRHs) transmit jointly. In these embodiments, the joint transmissions may be MIMO transmissions and the cooperating points are configured to perform joint beamforming.

LTE Channel Estimation

To facilitate the estimation of the channel characteristics LTE uses cell specific reference signals (i.e., pilot symbols) inserted in both time and frequency. These pilot symbols provide an estimate of the channel at given locations within a subframe. Through interpolation it is possible to estimate the channel across an arbitrary number of subframes. The pilot symbols in LTE are assigned positions within a subframe depending on the eNodeB cell identification number and which transmit antenna is being used, as shown in the figure below. The unique positioning of the pilots ensures that they do not interfere with one another and can be used to provide a reliable estimate of the complex gains imparted onto each resource element within the transmitted grid by the propagation channel.

To minimize the effects of noise on the pilot estimates, the least square estimates are averaged using an averaging window. This simple method produces a substantial reduction in the level of noise found on the pilots. There are two pilot symbol averaging methods available.

Time averaging is performed across each pilot symbol carrying subcarrier, resulting in a column vector containing an average amplitude and phase for each reference signal carrying subcarrier.

All the pilot symbols found in a subcarrier are time averaged across all OFDM symbols, resulting in a column vector containing the average for each reference signal subcarrier, The averages of the pilot symbol subcarriers are then frequency averaged using a moving window of maximum size.

In some embodiments, The PSS and SSS provide the cell station with its physical layer identity within the cell. The signals may also provide frequency and time synchronization within the cell. The PSS may be constructed from Zadoff-Chu (ZC) sequences and the length of the sequence may be predetermined (e.g., 62) in the frequency domain. The SSS uses two interleaved sequences (i.e., maximum length sequences (MLS), SRGsequences or m-sequences) which are of a predetermined length (e.g., 31). The SSS may be scrambled with the PSS sequences that determine physical layer ID. One purpose of the SSS is to provide the cell station with information about the cell ID, frame timing properties and the cyclic prefix (CP) length. The cell station may also be informed whether to use TDD or FD. In FDD, the PSS may be located in the last OFDM symbol in first and eleventh slot of the frame, followed by the SSS in the next symbol. In TDD, the PSS may be sent in the third symbol of the 3rd and 13th slots while SSS may be transmitted three symbols earlier. The PSS provided the cell station with information about to which of the three groups of physical layers the cell belongs to (3 groups of 168 physical layers). One of 168 SSS sequences may be decoded right after PSS and defines the cell group identity directly.

In some embodiments, the cell station may be configured in one of 8 "transmission modes" for PDSCH reception: Mode 1: Single antenna port, port **0**; Mode 2: Transmit diversity; Mode 3: Large-delay CDD; Mode 4: Closed-loop spatial multiplexing; Mode 5: MU-MIMO; Mode 6: Closed-loop spatial multiplexing, single layer; Mode 7: Single antenna port, cell station-specific RS (port **5**); Mode 8 (new in Rel-9): Single or dual-layer transmission with cell station-specific RS (ports **7** and/or **8**). The CSI-RS are used by the cell station for channel estimates (i.e., CQI measurements). In some embodiments, the CSI-RS are transmitted periodically in particular antenna ports (up to eight transmit antenna ports) at different subcarrier frequencies (assigned to the cell station) for use in estimating a MIMO channel. In some embodiments, a cell station-specific demodulation reference signal (e.g., a DM-RS) may be precoded in the same way as the data when non-codebook-based precoding is applied.

EXAMPLES

1. An example device comprising:

a transceiver;

a processor; and

a memory having instructions for execution by the processor to:

receive an indication of a subset of scheduling constraints for interference mitigation and cancelation; and

perform interference mitigation and cancelation utilizing the subset of scheduling constraints.

2. The example device of example 1 wherein the indication comprises an index corresponding to a subset of available scheduling parameters to be used in the performance of interference mitigation and cancelation.

3. The example device of example 2 wherein the processor further uses the index to access a table with multiple indexed sets of modulation coding scheme/resource combinations.

4. The example device of example 3 wherein the subset of modulation coding scheme/resource combinations comprise at least two modulation coding scheme/resources selected from the group consisting of MCS (modulation coding scheme), precoding (PMI—precoding matrix indicator) and frequency-time resources.

5. The example device of example 1 wherein the scheduling constraints specify that co-scheduled user equipment radio bands are totally overlapping.

6. The example device of example 5 wherein the scheduling constraints specify that co-scheduled user equipment radio bands are permitted to start from a mid-point of a radio band allocation and that the radio bands are continuous.

7. The example device of example 1 wherein the scheduling constraints specify that modulation orders of co-scheduled user equipment are within a limited range.

8. The example device of example 1 wherein the scheduling constraints specify that transmission modes are within a limited number of combinations.

9. The example device of example 1 wherein the scheduling constraints specify that a number of co-scheduled user equipment is limited.

10. An example method comprising:

receiving at a user equipment an indication of a subset of scheduling constraints for interference mitigation and cancelation; and performing interference mitigation and cancelation utilizing the subset of scheduling constraints.

11. The example method of example 10 wherein the indication comprises an index corresponding to a subset of available scheduling parameters to be used in the performance of interference mitigation and cancelation.

12. The example method of example 11 and further comprising using the index to access a table with multiple indexed sets of modulation coding scheme/resource combinations.

13. The example method of example 12 wherein the subset of modulation coding scheme/resource combinations comprise at least two modulation coding scheme/resources selected from the group consisting of MCS (modulation coding scheme), precoding (PMI—precoding matrix indicator) and frequency-time resources.

14. The example method of example 10 wherein the scheduling constraints for interference mitigation and cancelation are received by the user equipment in an interference-cooperation region between neighboring cells.

15. The example method of example 10 and further comprising:

exchanging information identifying an interference-cooperation region between neighboring cells; and

synchronizing scheduling constraints to propagate to user equipment in the interference-cooperation region.

16. The example method of example 15 wherein one scheduling constraint includes a radio band allocation starting from a specified set of radio bands.

17. The example method of example 15 wherein one scheduling constraint includes all user equipment within the interference-cooperation region using phase-shift keying.

18. An example base station comprising:

a transceiver;

a processor; and

a memory having instructions for execution by the processor to:

identify a subset of scheduling constraints for interference mitigation and cancelation; and

send an indication of the subset of scheduling constraints to multiple user equipment within a cell of the base station to enable the user equipment to perform interference mitigation and cancelation utilizing the subset of scheduling constraints.

19. The example base station of example 18 and wherein the processor further:

exchanges information identifying an interference-cooperation region between neighboring cells; and

synchronizes scheduling constraints to propagate to user equipment in the interference-cooperation region.

20. The example base station of example 15 wherein one subset of scheduling constraint includes a radio band allocation starting from a specified set of radio bands and that all user equipment within the interference-cooperation region use phase-shift keying.

In various embodiments, the scheduling constraint is on modulation/TM/MCS/PMI. In one example, the coordinated parameters are within a limited boundary of each other (as compared to the number of possibilities if there is no such coordination).

2-3 bits may be used to index into tables to limit the difference between co-scheduled UEs. The tables may be used to select a combination to limit the possible combinations between co-scheduled UEs (or the UEs scheduled on similar resources in a neighboring cell). So that an UE can figure out easily the scheduling combinations of the interfering signals. The set of tables may be used to limit the combination, with emphasis on modulation order, transmission mode and power difference, etc. Note the tables themselves have certain flexibility to accommodate changes. For example, in FIG. **5** "×dB" is used. Coordination may also be done across cells on an interference coordination region.

The foregoing description of one or more implementations provides illustration and description, but is not intended to be exhaustive or to limit the scope of the invention to the precise form disclosed. Modifications and variations are possible in light of the above teachings or may be acquired from practice of various implementations of the invention.

The invention claimed is:

1. A device comprising:

a transceiver;

a processor; and

a memory having instructions for execution by the processor to:

receive an indication of a subset of scheduling constraints for interference mitigation and cancelation, the indication being common to at least one other user equipment receiver and in the form of a downlink control indicator (DCI) with an index that corresponds to the subset of scheduling constraints in a locally stored table with multiple indexed sets of subsets of scheduling constraints corresponding to modulation/transmission mode/modulation coding scheme/precoding matrix indicator;

use the index to retrieve the subset of scheduling constraints from the table; and

perform interference mitigation and cancelation utilizing the subset of scheduling constraints by searching for use of the subset of scheduling constraints by others and mitigating the effect of used scheduling constraints in the subset of constraints.

2. The device of claim **1** wherein the subset of modulation coding scheme/resource combinations comprise at least two modulation coding scheme/resources selected from the group consisting of MCS (modulation coding scheme), precoding (PMI—precoding matrix indicator) and frequency-time resources.

3. The device of claim **1** wherein the scheduling constraints specify that co-scheduled user equipment radio bands are totally overlapping.

4. The device of claim **3** wherein the scheduling constraints specify that co-scheduled user equipment radio bands are permitted to start from a mid-point of a radio band allocation and that the radio bands are continuous.

5. The device of claim **1** wherein the scheduling constraints specify that modulation orders of co-scheduled user equipment are within a limited range.

6. The device of claim **1** wherein the scheduling constraints specify that transmission modes are within a limited number of combinations.

7. The device of claim **1** wherein the scheduling constraints specify that a number of co-scheduled user equipment is limited.

8. A method comprising:

receiving, at a user equipment, an indication of a subset of scheduling constraints for interference mitigation and cancelation, the indication being common to at least one other user equipment receiver and in the form of a downlink control indicator (DCI) with an index that corresponds to the subset of scheduling constraints in a locally stored table with multiple indexed sets of subsets of scheduling constraints corresponding to modulation/transmission mode/modulation coding scheme/precoding matrix indicator;

using the index to retrieve the subset of scheduling constraints from the table; and

performing interference mitigation and cancelation utilizing the subset of scheduling constraints by searching for use of the subset of scheduling constraints by others and mitigating the effect of used scheduling constraints in the subset of constraints.

9. The method of claim **8** wherein the subset of modulation coding scheme/resource combinations comprise at least two modulation coding scheme/resources selected from the group consisting of MCS (modulation coding scheme), precoding (PMI—precoding matrix indicator) and frequency-time resources.

10. The method of claim **8** wherein the scheduling constraints for interference mitigation and cancelation are received by the user equipment in an interference-cooperation region between neighboring cells.

11. The method of claim **8** and further comprising:

exchanging information identifying an interference-cooperation region between neighboring cells; and

synchronizing scheduling constraints to propagate to user equipment in the interference-cooperation region.

12. The method of claim **11** wherein one scheduling constraint includes a radio band allocation starting from a specified set of radio bands.

13. The method of claim **11** wherein one scheduling constraint includes all user equipment within the interference-cooperation region using phase-shift keying.

14. A base station comprising:

a transceiver;

a processor; and

a memory having instructions for execution by the processor to:

identify a subset of scheduling constraints for interference mitigation and cancelation, the subset of scheduling constraints reducing the search space for a user equipment searching of uses of scheduling constraints to countermand interference resulting from the uses; and

send an indication of the subset of scheduling constraints to multiple user equipments within a cell of the base station to enable the user equipment to perform interference mitigation and cancelation utilizing the subset of scheduling constraints, the indication in the form of a downlink control indicator (DCI) with an index that corresponds to the subset of scheduling constraints in a table stored on the multiple user equipments, the table including multiple indexed sets of subsets of scheduling constraints corresponding to modulation/transmission mode/modulation coding scheme/precoding matrix indicator.

15. The base station of claim **14** and wherein the processor further:

exchanges information identifying an interference-cooperation region between neighboring cells; and

synchronizes scheduling constraints to propagate to user equipment in the interference-cooperation region.

16. The base station of claim **14** wherein one subset of scheduling constraint includes a radio band allocation starting from a specified set of radio bands and that all user equipment within the interference-cooperation region use phase-shift keying.

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