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(54) **Title:** METHODS, DEVICES AND COMPUTER READABLE MEDIUM FOR INTERFERENCE MEASUREMENTS IN COMMUNICATION NETWORKS

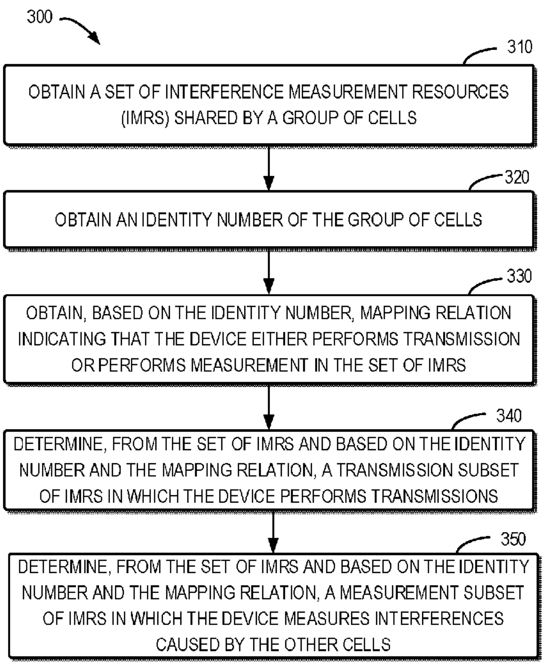

FIG. 3

(57) **Abstract:** Embodiments of the present disclosure provide methods, devices and computer readable medium for interference measurements in communication systems. According to embodiments of the present disclosure, the device determines the IMR used for interference measurements based on an IMR configuration matrix. According to embodiments of the present disclosure, the capability of interference measurement is scaled up in a balanced way. The consumption of resources for interference measurements is reduced significantly.

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METHODS, DEVICES AND COMPUTER READABLE MEDIUM FOR INTERFERENCE MEASUREMENTS IN COMMUNICATION NETWORKS

FIELD

[0001] Embodiments of the present disclosure generally relate to communication techniques, and more particularly, to methods, devices and computer readable medium for interference measurements in communication networks.

BACKGROUND

[0002] Channel State Information (CSI) reports, irrespective of whether they are aperiodic or periodic, need measurements of channel properties, as well as the interference level. Measuring the interference level is more cumbersome and the measurement is significantly affected by the transmission activity in neighboring cells, such as cooperation selection in Coordinated Multi-Point (CoMP) and link direction assignment in dynamic Time Division Duplex (TDD). In practice, interferences are measured as the noise on the Cell-specific Reference Signals (CRS). That is, the residual after subtracting the reference signal from the received signal in the appropriate resource elements is used as an estimate of the interference level. At low loads, this approach unfortunately often results in overestimating the interference level since the measurements are dominated by CRS transmissions in neighboring cells (assuming the same CRS positions in the neighboring cells), irrespective of the actual load in those cells. Furthermore, the device may also choose to average the interference level across multiple subframes, further adding to the uncertainty on how the interference is measured by the device.

SUMMARY

[0003] Generally, embodiments of the present disclosure relate to a method for interference measurements in communication networks.

[0004] In a first aspect, embodiments of the disclosure provide a device. The device comprises: at least one processor; at least one memory including computer program codes; the at least one memory and the computer program codes are configured to, with the at least one processor, cause the device at least to obtain a set of IMRs shared by a group of cells. The device is located in a cell of the group of cells. Each of the group of cells is associated with an identity number. The device is further caused to obtain an identity number of the cell. The device is further caused to obtain, based on the identity number, mapping relation indicating that the device either performs transmission or performs measurement in the set of IMRs. The device is also caused to determine, from the set of IMRs and based on the identity number and the mapping relation, a transmission subset of IMRs in which the device performs transmissions. The device is further caused to determine, from the set of IMRs and based on the identity number and the mapping relation, a measurement subset of IMRs in which the device measures interferences caused by the other cells.

[0005] In a second aspect, embodiments of the present disclosure provide a method. The method comprises obtaining, at a device, a set of Interference Measurement Resources (IMRs) shared by a group of cells. The device is located in a cell of the group of cells. Each of the group of cells is associated with an identity number. The method further comprises obtaining an identity number of the cell. The method comprises obtain, based on the identity number, mapping relation indicating that the device either performs transmissions or performs measurement in the set of IMRs. The method also comprises determining, from the set of IMRs and based on the identity number and the mapping relation, a transmission subset of IMRs in which the device performs transmissions. The method further comprises determining, from the set of IMRs and based on the identity number and the mapping relation, a measurement subset of IMRs in which the device measures interferences caused by the other cells.

[0006] In a third aspect, embodiments of the disclosure provide an apparatus. The apparatus comprises means for means for obtaining, at a device, a set of IMRs shared by a group of cells. The device is located in a cell of the group of cells. Each of the group of cells is associated with an identity number. The apparatus also comprises means for obtaining an identity number of the cell. The apparatus also comprises means for obtaining, based on the identity number, mapping relation indicating that the device either performs transmissions or performs measurement in the set of IMRs. The apparatus further comprises means for determining, from the set of IMRs and based on the identity number and the mapping relation, a transmission subset of IMRs in which the device performs transmissions. The apparatus also comprises means for determining, from the set of IMRs and based on the identity number and the mapping relation, a measurement subset of IMRs in which the device measures interferences caused by the other cells.

[0007] In a fourth aspect, embodiments of the disclosure provide a computer readable medium. The non-transitory computer-readable medium stores instructions for causing an apparatus to perform obtaining, at a device, a set of IMRs shared by a group of cells. The device is located in a cell of the group of cells. Each of the group of cells is associated with an identity number. The apparatus is further caused to perform obtaining an identity number of the cell. The apparatus is further caused to perform obtaining, based on the identity number, mapping relation indicating that the device either performs transmissions or performs measurement in the set of IMRs. The apparatus is further caused to perform determining, from the set of IMRs and based on the identity number and the mapping relation, a transmission subset of IMRs in which the device performs transmissions. The apparatus is also caused to perform determining, from the set of IMRs and based on the identity number and the mapping relation, a measurement subset of IMRs in which the device measures interferences caused by the other cells.

[0008] Other features and advantages of the embodiments of the present disclosure will also be apparent from the following description of specific embodiments when read in conjunction with the accompanying drawings, which illustrate, by way of example, the principles of embodiments of the disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] Embodiments of the disclosure are presented in the sense of examples and their advantages are explained in greater detail below, with reference to the accompanying drawings, where

[0010] Figs. 1A and 1B illustrates schematic diagrams of network deployments according to conventional technologies;

[0011] Fig. 2 illustrates a schematic diagram of a communication system according to according to embodiments of the present disclosure;

[0012] Fig. 3 illustrates a flowchart of a method according to embodiments of the present disclosure;

[0013] Fig. 4 illustrates a schematic diagram of a communication system according to embodiments of the present disclosure; and

[0014] Fig. 5 illustrates a schematic diagram of a device according to embodiments of the present disclosure.

[0015] Throughout the figures, same or similar reference numbers indicate same or similar elements.

DETAILED DESCRIPTION OF EMBODIMENTS

[0016] The subject matter described herein will now be discussed with reference to several example embodiments. It should be understood these embodiments are discussed only for the purpose of enabling those skilled persons in the art to better understand and thus implement the subject matter described herein, rather than suggesting any limitations on the scope of the subject matter.

[0017] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of example embodiments. As used herein, the singular forms "a," "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises," "comprising," "includes" and/or "including," when used herein, specify the presence of stated features, integers, steps, operations, elements and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components and/or groups thereof.

[0018] It should also be noted that in some alternative implementations, the functions/acts noted may occur out of the order noted in the figures. For example, two functions or acts shown in succession may in fact be executed concurrently or may sometimes be executed in the reverse order, depending upon the functionality/acts involved.

[0019] As used herein, the term "communication network" refers to a network following any suitable communication standards, such as Long Term Evolution (LTE),

LTE-Advanced (LTE-A), Wideband Code Division Multiple Access (WCDMA), High-Speed Packet Access (HSPA), Wireless Fidelity (Wi-Fi), and so on. Furthermore, the communications between a terminal device and a network device in the communication network may be performed according to any suitable generation communication protocols, including, but not limited to, the first generation (1G), the second generation (2G), 2.5G, 2.75G, the third generation (3G), the fourth generation (4G), 4.5G, the future fifth generation (5G) communication protocols, IEEE 802.11 protocols, and/or any other protocols either currently known or to be developed in the future.

[0020] Embodiments of the present disclosure may be applied in various communication systems. Given the rapid development in communications, there will of course also be future type communication technologies and systems with which the present disclosure may be embodied. It should not be seen as limiting the scope of the present disclosure to only the aforementioned system.

[0021] The term "device" used herein refers to any proper devices which are capable of communication. For example, the term "device" may refer to a network device or a terminal device. The term "network device" includes, but not limited to, a base station (BS), a gateway, a management entity, and other suitable device in a communication system. The term "base station" or "BS" represents a node B (NodeB or NB), an evolved NodeB (eNodeB or eNB), a NR NodeB (gNB), a Remote Radio Unit (RRU), a radio header (RH), a remote radio head (RRH), a relay, a low power node such as a femto, a pico, a router and so forth.

[0022] The term "terminal device" includes, but not limited to, "user equipment (UE)" and other suitable end device capable of communicating with the network device. By way of example, the "terminal device" may refer to a terminal, a Mobile Terminal (MT), a Subscriber Station (SS), a Portable Subscriber Station, a Mobile Station (MS), or an Access Terminal (AT).

[0023] The term "circuitry" used herein may refer to one or more or all of the following:

[0024] (a) hardware-only circuit implementations (such as implementations in only analog and/or digital circuitry) and

[0025] (b) combinations of hardware circuits and software, such as (as applicable):

[0026] (i) a combination of analog and/or digital hardware circuit(s) with software/firmware and

[0027] (ii) any portions of hardware processor(s) with software (including digital signal processor(s)), software, and memory(ies) that work together to cause an apparatus, such as a mobile phone or server, to perform various functions) and

[0028] (c) hardware circuit(s) and or processor(s), such as a microprocessor(s) or a portion of a microprocessor(s), that requires software (e.g., firmware) for operation, but the software may not be present when it is not needed for operation."

[0029] This definition of circuitry applies to all uses of this term in this application, including in any claims. As a further example, as used in this application, the term circuitry also covers an implementation of merely a hardware circuit or processor (or multiple processors) or portion of a hardware circuit or processor and its (or their) accompanying software and/or firmware. The term circuitry also covers, for example and if applicable to the particular claim element, a baseband integrated circuit or processor integrated circuit for a mobile device or a similar integrated circuit in server, a cellular network device, or other computing or network device.

[0030] As mentioned above, conventional interference measurements may not be accurate. To address these shortcomings and to better support various CoMP schemes, transmission mode 10 which is introduced in release 11 in the 3GPP provides tools for the network to control on which resource elements the interference is measured. The basis is called CSI interference measurement (CSI-IM) configuration. A CSI-IM configuration is a set of resource elements in one subframe in which the device should use for measuring interference. The received power in the resource elements corresponding to the CSI-IM configuration is used as an estimate of the interference (and noise). The single subframe in which the interference should be measured is also specified, thereby avoiding device-specific, and to the network unknown, interference averaging across subframes.

[0031] In the 3GPP Long Term Evolution (LTE) release 11, configuring a CSI-IM is done in a similar way as a CSI-RS and the same set of configurations is available. In practice, a CSI-IM resource may typically correspond to a CSI-RS resource in which nothing is transmitted from the cell. Thus, the CSI-IM resource may typically be covered by the set of zero-power CSI-RS resources configured for the device. However, CSI-IM and zero-power CSI-RS serve different purposes. The CSI-IM is defined in order to specify a set of resource elements on which a device should measure the interference level while the zero-power CSI-RS is defined in order to specify a set of resource elements avoided by the Physical Downlink Shared Channel (PDSCH) mapping. Since the CSI-IM does not collide with the CRS in neighboring cells but rather the PDSCH (assuming a synchronized network), the interference measurement better reflects the transmission activity in neighboring cells, leading to a more accurate interference estimate at low loads. Hence, with the channel conditions estimated from the CSI-RS and the interference situation estimated from the CSI-IM, the network has detailed control of the interference situation the CSI report reflects. In New Radio (NR) release 15, the terminal device can be independently configured with one or more CSI-IM resource set configuration as indicated by the higher layer parameter CSI-IM-ResourceSet.

[0032] For CoMP and various beamforming schemes, the network device (for example, a gNB) benefits from multiple CSI reports, derived under different interference hypotheses. To maximize flexibility in scheduling in the network, the CSI of all possible transmission hypotheses should be reported by the terminal devices. However, the conventional CSI process approach and CSI-IM configuration may lack scalability. If coordination across a large number of nodes is desirable or a large number of potential beam-forming candidates are to be evaluated, there is an exponential increase in the number of CSI processes with a corresponding increase in the CSI-IM overhead. In addition, the demands in interference measurement overhead may be further exacerbated in dynamic TDD where the terminal device is not only required to estimate the downlink (DL) interference but also uplink (UL) interference potentially caused by all the terminal devices in the neighboring cells. The Release 15 NR TDD frame structure is very flexible, allowing for DL-only slots, UL-only slots, and bi-directional slots, which are combined to form radio frames. In NR, Orthogonal Frequency Division Multiplexing (OFDM) symbols in a slot can be classified as 'downlink', 'flexible', or 'uplink'. The misalignment in link direction among the neighboring cells raises the Cross-Link Interference (CLI) -- detrimental UE-UE and Transmission Reception

Point (TRP)-TRP interference. The CLI is prone to causing the majority of transmission failure in the dynamic TDD system. Therefore, a scalable IMR configuration with small measurement overhead for multiple transmission hypotheses is required in future NR releases.

[0033] For a cellular network with regular hexagonal deployment, one cell is largely interfered by 6 immediate next cells, the ICI caused by the other distant cells are so weak that they can be ignored, especially for macro cell scenario. To carry out CoMP and/or inter-cell interference coordination (ICIC) including CLI coordination, the expected interference measurement is designed to predict the interference level to be experienced by the transmission and identify the source cell causing the strong ICI.

[0034] The appropriate cooperation (CoMP transmission) scheme or link-direction assignment can be decided by predicting the interference level. The decision are actually made depending on the interference level corresponding to diverse transmission hypotheses, since the actual interference level may vary rapidly and in an (apparently) unpredictable way. For example, the cell 1 should measure the interference level under different transmission hypotheses of cells 2, 3, 4, 5, 6 and 7, where some of neighboring cells make transmission while the others keep silent. There occur at least 2^6-1 transmission hypotheses for cell 1, resulting in the prohibitive measurement cost. In practice, only the typical transmission hypotheses are considered.

[0035] In conventional technologies, in order to exactly find out a source cell, out of 6 cells, that causes the third strongest interference at least, we need to exactly estimate 4 interference sources in general. The measurement overhead becomes unacceptable when all cells pursue the same measurement procedure.

[0036] Although there are a plenty of technologies related to IMR assignment to predict the interference level under different transmission hypotheses, the conventional methods lack the scalability and incur a rise in measurement overhead for large coordination area. They are suitable for the small coordination area, even though they can be extended for large coordination area in conjunction with clustering method.

[0037] Fig. 1A illustrates a schematic diagram of a network with regular hexagonal deployment according to conventional technologies. For the separated cell clusters {1, 4, 5, 6, 13, 14, 15}, {7, 17, 18, 19, 34, 35, 36} and {2, 3, 8, 9, 10, 21, 22}, as shown in Fig 1A, the IMR used for these 3 clusters are orthogonal to each other. Each cluster can apply the conventional IMR assignment for interference measurement. However, the separated clustering method resulting in boundary effect, that is, the boundary cell cannot measure the interference to be experienced. This means that the cells are configured with non-uniform capability of interference measurement, leading to non-uniform service in the coverage.

[0038] Fig. 1B illustrates a schematic diagram of a network with regular hexagonal deployment according to conventional technologies. As shown in Fig. 1B, the overlapped clustering technology may remove the boundary effect. However, the overhead of IMR may be increased proportional to the size of network, resulting in extra and undesirable costs.

[0039] On the other hand, in order to identify the strong ICI, the conventional direct measurement technology is usually considered by measuring the individual inference in one-by-one fashion. The measurement period is inevitably across multiple subframes during which the scheduled terminal devices and transmission activities may be varied in practical application, which is incompatible with the above measurement procedure. However, in case of highly dynamic traffic conditions, the traffic activity of neighbor transmission points may vary rapidly. As a consequence, the interference information would be outdated and meaningless for network to make right scheduling decision.

[0040] In order to at least in part solve above and other potential problems, embodiments of the present disclosure provide solutions for interference measurements. Now some example embodiments of the present disclosure are described below with reference to the figures. However, those skilled in the art would readily appreciate that the detailed description given herein with respect to these figures is for explanatory purpose as the present disclosure extends beyond theses limited embodiments.

[0041] According to embodiments of the present disclosure, the device determines the IMR used for interference measurements based on an IMR configuration matrix. According to embodiments of the present disclosure, the capability of interference measurement is scaled up in a balanced way. The consumption of resources for interference measurements is reduced significantly.

[0042] FIG. 2 illustrates a schematic diagram of a communication system in which embodiments of the present disclosure can be implemented. The communication system 200, which is a part of a communication network, comprises a device 210-1, a device 210-2, ... , a device 210-N, which can be collectively referred to as "device(s) 210." The communication system also comprises a cell 230-1, a cell 230-2, . . . , a cell 230-N, which can be collectively referred to as "cell(s) 230." It is to be understood that the number of devices and cells shown in FIG. 2 is given for the purpose of illustration without suggesting any limitations. The communication system 100 may comprise any suitable number of devices and cells.

[0043] It should be noted that the communication system 100 may also comprise other elements, for example, a network device 220-1, a network device 220-2, a network device 220-3, a network device 220-4, a network device 220-5, a network device 220-6, a network device 220-7, . . . , a network device 220-N. The number of terminal device 230 shown in Fig. 2 is given for the purpose of illustration without suggesting any limitations.

[0044] Communications in the communication system 200 may be implemented according to any proper communication protocol(s), comprising, but not limited to, cellular communication protocols of the first generation (1G), the second generation (2G), the third generation (3G), the fourth generation (4G) and the fifth generation (5G) and on the like, wireless local network communication protocols such as Institute for Electrical and Electronics Engineers (IEEE) 802.11 and the like, and/or any other protocols currently known or to be developed in the future. Moreover, the communication may utilize any proper wireless communication technology, comprising but not limited to: Code Divided Multiple Address (CDMA), Frequency Divided Multiple Address (FDMA), Time Divided Multiple Address (TDMA), Frequency Divided Duplexer (FDD), Time Divided Duplexer (TDD), Multiple-Input Multiple-Output (MIMO), Orthogonal Frequency Divided Multiple Access (OFDMA) and/or any other technologies currently known or to be developed in the future.

[0045] Fig. 3 illustrates a flow chart of a method of 300 according to embodiments of the present disclosure. The method 300 may be implemented at any devices in the group of devices 210. Only for the purpose of illustrations, embodiments of the present disclosure are described to be implemented at the device 210-1.

[0046] At block 310, the device 210-1 obtains a set of IMRs shared by the group of cells 230. In some embodiments, in order to facilitate UL and DL interference measurements, each IMR is configured for one cell to specify a subset of resource elements (REs) avoided by the PDSCH/PUSCH mapping. In some embodiments, the number of cells in the group of cells 230 is seven. Each cell in the group of cells 230 has an identity number. For example, the cell 230-1 has the identity number "1."

[0047] In an example embodiment, the IMRs in the set of IMRs are orthogonal to each other and the number of IMRs is seven. For example, the IMRs may occupy the same subcarrier but across 7 consecutive OFMD symbols. One Interference Measurement Period (IMP) comprises seven consecutive OFDM symbols which include seven IMRs and corresponding to one slot in LTE or NR system.

[0048] At block 320, the device 210-1 obtains an identity of the cell. In some embodiments, the identity of the cell 230-1 may be configured by a high-layer signaling based on geometrical relation. In other embodiments, the identity of the cell 230-1 may be coordinated among the cells.

[0049] At block 320, the device210-1 obtains, based on the identity number, mapping relation indicating that the device either performs transmission or performs measurement in the set of IMRs.

[0050] In an example embodiment, the mapping relation may be Table 1 below.

Table 1

	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7
IMR 1	1	1	0	1	0	0	0
IMR 2	1	0	1	0	0	0	1
IMR 3	1	0	0	0	1	1	0
IMR 4	0	1	1	0	1	0	0
IMR 5	0	1	0	0	0	1	1
IMR 6	0	0	1	1	0	1	0
IMR 7	0	0	0	1	1	0	1

[0051] In the above Table 1, element "0" represents the device should perform measurements while element "1" represents that the device should perform transmission. In some embodiment, the mapping relation may be determined based on a Balanced Incomplete Block Design (BIBD) theory. In some embodiments, the order of cell identity number in the first row can be rearranged and the order of IMR in the first column can also be rearranged.

[0052] In some embodiments, the group of cells with different seven identity numbers uses seven different mapping relations to configure seven different IMRs. In this way, each cell performs transmission in 3 different IMRs, 3 different cells perform transmission in each IMR, and any two distinct cells perform one concurrent transmission in seven IMRs.

[0053] In an example embodiment, the mapping relation may be obtained from a high-layer signaling. . In other embodiment, the mapping relation may be coordinated among the cells.

[0054] Fig. 4 illustrates a schematic diagram of configurations for cell identity number for interference measurement according to embodiments of the present disclosure. As shown in Fig. 4, a cluster of seven neighboring hexagonal cells is configured with cell identity {1, 2, 3, 4, 5, 6, 7}. For the purpose of illustrations, the identity of the cell 230-1 is "1."

[0055] At block 340, the device 210-1 determine, from the set of IMRs and based on the identity number and the mapping relation, a transmission subset of IMRs in which the device performs transmissions. In some embodiments, the device in each cell is equally assigned with 4 IMRs for interference measurement during one IMP, the device in each cell is to be measured equally by 3 times during one IMP, and the device in each cell measures the interference level under the similar transmission hypotheses with 3 active transmissions.

[0056] At block 350, the device 210-1 determines, from the set of IMRs and based on the identity number and the mapping relation, a measurement subset of IMRs in which the device measures interferences caused by the other cells.

[0057] For example, the device 210-1 may determine the IMR 4, IMR5, IMR6 and IMR7 as the measurement subset of the IMRs based on the Table 1 and the identity number "1." The device 210-1 may determine the IMR 1, IMR2 and IMR3 as the transmission subset of the IMRs based on the Table 1 and the identity number "1."

[0058] For example, in IMR 1, the cells 230-1, 230-2 and 230-4 make DL/UL transmission while the devices 210-3, 210-5, 210-6 and 210-7 associated with cells 3, 5, 6, and 7 measure the corresponding interference, simultaneously.

[0059] In IMR 2, the cells 230-1, 230-3 and 230-7 make DL/UL transmission while the devices 210-2, 210-4, 210-5 and 210-6 associated with cells 2, 4, 5, and 6 measure the corresponding interference, simultaneously.

[0060] In IMR 3, the cells 230-1, 230-5 and 230-6 make DL/UL transmission while the devices 210-2, 210-3, 210-4 and 210-7 associated with cells 2, 3, 4, and 7 measure the corresponding interference, simultaneously.

[0061] In IMR 4, the cells 230-2, 230-3 and 230-5 make DL/UL transmission while the devices 210-1, 210-4, 210-6 and 210-7 associated with cells 1, 4, 6, and 7 measure the corresponding interference, simultaneously.

[0062] In IMR 5, the cells 230-2, 230-6 and 230-7 make DL/UL transmission while the devices 210-1, 210-3, 210-4 and 210-5 associated with cells 1, 3, 4, and 5 measure the corresponding interference, simultaneously.

[0063] In IMR 6, the cells 230-3, 230-4 and 230-6 make DL/UL transmission while the devices 210-1, 210-2, 210-5 and 210-7associated with cells 1, 2, 5, and 7 measure the corresponding interference, simultaneously.

[0064] In IMR 7, the cells 230-4, 230-5 and 230-7 make DL/UL transmission while the devices 210-1, 210-2, 210-3 and 210-6 associated with cells 1, 2, 3, and 6 measure the corresponding interference, simultaneously.

[0065] In this way, the interference measurement capability can be scaled up in a balanced way, benefitting the good property in BIBD. It provides every cell with the similar/same capability of interference measurement.

[0066] The configuration matrix in Table 1 maintains the good balanced properties even while permuting the rows and columns. Thus, the configuration matrix in Table 1 may be readily applied to the whole network by taking advantage of the geometric property in cellular network. The entire network only adopts the 7 cell identity numbers, that is, {1, 2, 3, 4, 5, 6, 7}, they are reused by the different cells as shown in Fig. 4. Such a reusing way allows any cell and its 6 immediately surrounding cells to form a 7-cell cluster that are associated with 7 different identity numbers, i.e. {1, 2, 3, 4, 5, 6, 7}, even though the identity number of center cell is no longer fixed.

[0067] The cells with the same identity number employ the same IMR configuration according to the above Table 1. Accordingly, any cell not only measures the inference from its surrounding cells, but also can be measured by them similarly. As a consequence, every cell exhibits the same balanced properties of interference measurement as discussed, but also the 7 IMRs are re-exploited by entire network.

[0068] In some embodiments the device 210-1 may measure interferences on the device 210-1 caused by other cells in the group of cells 230 using the first IMRs. For example, the device 210-1 associated with the cell 230-1 estimates the interference power in IMRs 4, 5, 6, and 7; the device 210-2 associated with the cell 230-2 estimates the interference power in IMRs 2, 3, 6, and 7; the device 210-3 associated with the cell 230-3 estimates the interference power in IMRs 1, 3, 5, and 7; the device 210-4 associated with the cell 230-4 estimates the interference power in IMRs 2, 3, 4, and 5; the device 210-5 associated with the cell 230-5 estimates the interference power in IMRs 1, 2, 5, and 6; the device 210-6 associated with the cell 230-6 estimates the interference power in IMRs 1, 2, 4, and 7; and the device 210-7 associated with the cell 230-7 estimates the interference power in IMRs 1, 3, 4, and 6.

[0069] Assume that the device 210-k (where k belongs to a integer number) associated the cell 230-k experiences the DL/UL interference power $p_{k,j}$ due to its immediately surrounding cell with identity number j. As a result, the cell 230-k obtains the measured power vector $\mathbf{r}_k$ in terms of the following formula (1).

$$\mathbf{r}_k = \mathbf{M}_k \mathbf{p}_{k-} + \mathbf{n}_k, \quad k = 1, 2, \cdots, 7 \qquad (1)$$

where $\mathbf{M}_k$ denote the measurement matrix for the cell 230-k. It is a submatrix derived from $\mathbf{M}_{\text{IMR}}$ by properly deleting certain rows and columns. The Tables 2-8 show the measurement matrix for each device 210 in the cell 230.

Table 2: Measurement matrix for the cell 230-1 $\mathbf{M}_1$

	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7
IMR 4	1	1	0	1	0	0
IMR 5	1	0	0	0	1	1

IMR 6	0	1	1	0	1	0
IMR 7	0	0	1	1	0	1

Table 3: Measurement matrix for the cell 230-2 $\mathbf{M}_2$

	Cell 1	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7
IMR 2	1	1	0	0	0	1
IMR 3	1	0	0	1	1	0
IMR 6	0	1	1	0	1	0
IMR 7	0	0	1	1	0	1

Table 4: Measurement matrix for cell 230-3 $\mathbf{M}_3$

	Cell 1	Cell 2	Cell 4	Cell 5	Cell 6	Cell 7
IMR 1	1	1	1	0	0	0
IMR 3	1	0	0	1	1	0
IMR 5	0	1	0	0	1	1
IMR 7	0	0	1	1	0	1

Table 5: Measurement matrix for cell 230-4 $\mathbf{M}_4$

	Cell 1	Cell 2	Cell 3	Cell 5	Cell 6	Cell 7
IMR 2	1	0	1	0	0	1
IMR 3	1	0	0	1	1	0
IMR 4	0	1	1	1	0	0
IMR 5	0	1	0	0	1	1

Table 6: Measurement matrix for cell 230-5 $\mathbf{M}_5$

	Cell 1	Cell 2	Cell 3	Cell 4	Cell 6	Cell 7
IMR 1	1	1	0	1	0	0
IMR 2	1	0	1	0	0	1
IMR 5	0	1	0	0	1	1
IMR 6	0	0	1	1	1	0

Table 7: Measurement matrix for cell 230-6 $\mathbf{M}_6$

	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 7
IMR 1	1	1	0	1	0	0
IMR 2	1	0	1	0	0	1
IMR 4	0	1	1	0	1	0
IMR 7	0	0	0	1	1	1

Table 8: Measurement matrix for cell 230-7 $\mathbf{M}_7$

	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6
IMR 1	1	1	0	1	0	0
IMR 3	1	0	0	0	1	1
IMR 4	0	1	1	0	1	0
IMR 6	0	0	1	1	0	1

[0070] Vector $\mathbf{n}_k$ denotes the estimation error vector incurred by the cell 230-k. The vectors of interference power $\mathbf{p}_{k-}$'s are shown below.

$$\begin{aligned}
\mathbf{p}_{1-} &= \begin{bmatrix} p_{1,2} & p_{1,3} & p_{1,4} & p_{1,5} & p_{1,6} & p_{1,7} \end{bmatrix}^T \\
\mathbf{p}_{2-} &= \begin{bmatrix} p_{2,1} & p_{2,3} & p_{2,4} & p_{2,5} & p_{2,6} & p_{2,7} \end{bmatrix}^T \\
\mathbf{p}_{3-} &= \begin{bmatrix} p_{3,1} & p_{3,2} & p_{3,4} & p_{3,5} & p_{3,6} & p_{3,7} \end{bmatrix}^T \\
\mathbf{p}_{4-} &= \begin{bmatrix} p_{4,1} & p_{4,2} & p_{4,3} & p_{4,5} & p_{4,6} & p_{4,7} \end{bmatrix}^T . \\
\mathbf{p}_{5-} &= \begin{bmatrix} p_{5,1} & p_{5,2} & p_{5,3} & p_{5,4} & p_{5,6} & p_{5,7} \end{bmatrix}^T \\
\mathbf{p}_{6-} &= \begin{bmatrix} p_{6,1} & p_{6,2} & p_{6,3} & p_{6,4} & p_{6,5} & p_{6,7} \end{bmatrix}^T \\
\mathbf{p}_{7-} &= \begin{bmatrix} p_{7,1} & p_{7,2} & p_{7,3} & p_{7,4} & p_{7,5} & p_{7,6} \end{bmatrix}^T
\end{aligned}$$

[0071] In some embodiments, the device 210-1 may estimate an interference caused by each cell in the group based on the measured interferences and determine a device with a strongest interference based on the estimation. For example, the device 210-k in the cell 230-k estimates the individual interference power $\mathbf{p}_{k-}$ by solving the formula (2).

$$\hat{\mathbf{p}}_{k-} = \arg \min_{\mathbf{x} \in R_+^{6\times1}} \left\| \mathbf{M}_k \mathbf{x} - \mathbf{r}_k \right\|^2 \qquad (2)$$

where a favorable non-negative approximate vector is determined with least squares. The device 210-1 identifies the cell with the largest component in $\hat{\mathbf{p}}_{k-}$ as one source cell that impose the strong interference on the cell 230-1. In some embodiments, the device 210-1 may indicate the source cell to reduce the transmission power. In this way, the source cell can be identified with very small measurement overhead. In some embodiment, the linear system is constructed by the device to estimate unknown interferences based on the measurements in the measurement subset

[0072] In some embodiments, the device 210-1 may predict the interference level to be experienced under transmission hypotheses. From $\mathbf{r}_k$, the cell 210- k can immediately obtains the exact information about the interference level under 4 different transmission hypotheses, in each of which 3 surrounding cells make UL/DL transmissions while the other 3 cell keep silence. We can derive the rough information for more transmission hypotheses, by exploiting the algebraic structure in $\mathbf{M}_k$'s and the estimation information of $\hat{\mathbf{p}}_{k-}$. In this way, each cell can predict the exact interference level under 4 transmission hypotheses so that the appropriate cooperation (CoMP transmission) scheme or link-direction assignment can be decided.

[0073] According to embodiments of the present disclosure, good scalability for interference measurement can be achieved. It merely pays 7 IMRs to predict the interference level under the various transmission hypotheses and to enable multiple CSI processes. It has the following advantages of scalability, accuracy, and overhead.

[0074] For measurement accuracy, each cell has the similar performance against the estimation error, which can be demonstrated by the fact the different matrices $\mathbf{M}_k$'s have the same set of singular values {2.4495, 1.4142, 1.4142, 1.4142}.

[0075] It is able to identify the strong ICI sources with small measurement overhead.

[0076] In some embodiments, an apparatus for performing the method 300 (for example, the device 210-1) may comprise respective means for performing the corresponding steps in the method 300. These means may be implemented in any suitable manners. For example, it can be implemented by circuitry or software modules.

[0077] In some embodiments, the apparatus comprises means for obtaining, at a device, a set of IMRs shared by a group of cells, the device being located in a cell of the group of cells, each of the group of cells being associated with an identity number; means for obtaining an identity number of the cell; means for obtaining, based on the identity number, mapping relation indicating that the device either performs transmission or performs measurement in the set of IMRs means for determining, from the set of IMRs and based on the identity number and the mapping relation, a transmission subset of IMRs in which the device performs transmissions ; means for determining, from the set of IMRs and based on the identity number and the mapping relation, a measurement subset of IMRs in which the device measures interferences caused by the other cells.

[0078] In some embodiments, the apparatus further comprises means for determining, based on the identity, a transmission subset of IMRs different from the measurement subset of IMRs; and means for performing transmissions using the transmission subset of IMRs.

[0079] In some embodiments, wherein seven identity numbers are reused for all cells in a network based on geometrical relation, seven IMRs are reused for all cells, and cells associated with the same identity number uses the same mapping relation.

[0080] In some embodiments, wherein the group of cells with seven different identity numbers uses seven different mapping relations to configure seven different IMRs, respectively, such that each cell performs transmission in 3 different IMRs, 3 different cells performs transmission in each IMR, and any two distinct cells performs one concurrent transmission in seven IMRs.

[0081] In some embodiments, wherein a liner system is constructed by the device to estimate unknown interferences based on the measurements in the measurement subset.

[0082] In some embodiments, the apparatus further comprises means for estimating, based on the measured interferences, an interference caused by each cell in the group; means for determining a cell with a strongest interference power based on the estimation; and means for causing transmission power of the determined cell to be reduced.

[0083] Fig. 5 is a simplified block diagram of a device 500 that is suitable for implementing embodiments of the present disclosure. The device 500 may be implemented at the device 210-1. As shown, the device 500 includes one or more processors 510, one or more memories 520 coupled to the processor(s) 510, one or more transmitters and/or receivers (TX/RX) 540 coupled to the processor 510.

[0084] The processor 510 may be of any type suitable to the local technical network, and may include one or more of general purpose computers, special purpose computers, microprocessors, digital signal processors (DSPs) and processors based on multicore processor architecture, as non-limiting examples. The device 500 may have multiple processors, such as an application specific integrated circuit chip that is slaved in time to a clock which synchronizes the main processor.

[0085] The memory 520 may be of any type suitable to the local technical network and may be implemented using any suitable data storage technology, such as a non-transitory computer readable storage medium, semiconductor based memory devices, magnetic memory devices and systems, optical memory devices and systems, fixed memory and removable memory, as non-limiting examples.

[0086] The memory 520 stores at least a part of a program 530. The TX/RX 540 is for bidirectional communications. The TX/RX 540 has at least one antenna to facilitate communication, though in practice an Access Node mentioned in this application may have several ones. The communication interface may represent any interface that is necessary for communication with other network elements.

[0087] The program 530 is assumed to include program instructions that, when executed by the associated processor 510, enable the device 500 to operate in accordance with the embodiments of the present disclosure, as discussed herein with reference to Fig. 3. That is, embodiments of the present disclosure can be implemented by computer software executable by the processor 510 of the device 500, or by hardware, or by a combination of software and hardware.

[0088] While this specification contains many specific implementation details, these should not be construed as limitations on the scope of any disclosure or of what may be claimed, but rather as descriptions of features that may be specific to particular embodiments of particular disclosures. Certain features that are described in this specification in the context of separate embodiments can also be implemented in combination in a single embodiment. Conversely, various features that are described in the context of a single embodiment can also be implemented in multiple embodiments separately or in any suitable sub-combination. Moreover, although features may be described above as acting in certain combinations and even initially claimed as such, one or more features from a claimed combination can in some cases be excised from the combination, and the claimed combination may be directed to a sub-combination or variation of a sub-combination.

[0089] Similarly, while operations are depicted in the drawings in a particular order, this should not be understood as requiring that such operations be performed in the particular order shown or in sequential order, or that all illustrated operations be performed, to achieve desirable results. In certain circumstances, multitasking and parallel processing may be advantageous. Moreover, the separation of various system components in the embodiments described above should not be understood as requiring such separation in all embodiments, and it should be understood that the described program components and systems can generally be integrated together in a single software product or packaged into multiple software products.

[0090] Various modifications, adaptations to the foregoing exemplary embodiments of this disclosure may become apparent to those skilled in the relevant arts in view of the foregoing description, when read in conjunction with the accompanying drawings. Any and all modifications will still fall within the scope of the non-limiting and exemplary embodiments of this disclosure. Furthermore, other embodiments of the disclosures set forth herein will come to mind to one skilled in the art to which these embodiments of the disclosure pertain having the benefit of the teachings presented in the foregoing descriptions and the associated drawings.

[0091] Therefore, it is to be understood that the embodiments of the disclosure are not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. Although specific terms are used herein, they are used in a generic and descriptive sense only and not for purpose of limitation.

WHAT IS CLAIMED IS:

1. A device, comprising:

at least one processor; and

at least one memory including computer program codes;

the at least one memory and the computer program codes are configured to, with the at least one processor, cause the device at least to:

obtain a set of IMRs shared by a group of cells, the device being located in a cell of the group of cells, each of the group of cells being associated with an identity number;

obtain an identity number of the cell;

obtain, based on the identity number, mapping relation indicating that the device either performs transmission or performs measurement in the set of IMRs;

determine, from the set of IMRs and based on the identity number and the mapping relation, a transmission subset of IMRs in which the device performs transmissions; and

determine, from the set of IMRs and based on the identity number and the mapping relation, a measurement subset of IMRs in which the device measures interferences caused by the other cells.

2. The device of claim 1, wherein seven identity numbers are reused for all cells in a network based on geometrical relation, seven IMRs are reused for all cells, and cells associated with the same identity number uses the same mapping relation.

3. The device of claims 1 and 2, wherein the group of cells with seven different identity numbers uses seven different mapping relations to configure seven different IMRs, respectively, such that each cell performs transmission in 3 different IMRs, 3 different cells performs transmission in each IMR, and any two distinct cells performs one concurrent transmission in seven IMRs.

4. The device of any one of claims 1, 2 and 3, wherein a liner system is constructed by the device to estimate unknown interferences based on measurements in the measurement subset.

5. The device of claims 1 or 4, wherein the device is further caused to:

estimate, based on the measured interferences, an interference caused by each cell in the group;

determine a cell with a strongest interference power based on the estimation; and

cause transmission power of the determined cell to be reduced.

6. A method comprising:

obtaining, at a device, a set of IMRs shared by a group of cells, the device being located in a cell of the group of cells, each of the group of cells being associated with an identity number;

obtaining an identity number of the cell;

obtain, based on the identity number, mapping relation indicating that the device either performs transmissions or performs measurement in the set of IMRs;

determining, from the set of IMRs and based on the identity number and the mapping relation, a transmission subset of IMRs in which the device performs transmissions; and

determining, from the set of IMRs and based on the identity number and the mapping relation, a measurement subset of IMRs in which the device measures interferences caused by the other cells.

7. The method of claim 6, wherein seven identity numbers are reused for all cells in a network based on geometrical relation, seven IMRs are reused for all cells, and cells associated with the same identity number uses the same mapping relation.

8. The method of claims 6 or 7, wherein the group of cells with different seven identity numbers use seven different mapping relations to configure seven different IMRs, respectively, such that each cell performs transmission in 3 different

IMRs, 3 different cells performs transmission in each IMR, and any two distinct cells performs one concurrent transmission in seven IMRs.

9. The method of any one of claims 6, 7 and 8, wherein a liner system is constructed by the device to estimate unknown interferences based on measurements in the measurement subset.

10. The method of claims 6 or 9, further comprising:

estimating, based on the measured interferences, an interference caused by each cell in the group;

determining a cell with a strongest interference power based on the estimation; and

causing transmission power of the determined cell to be reduced.

11. A computer readable medium storing instructions thereon, the instructions, when executed by at least one processing unit of a machine, causing the machine to perform the method according to any one of claims 6-10.

12. An apparatus comprising:

means for obtaining, at a device, a set of IMRs shared by a group of cells, the device being located in a cell of the group of cells, each of the group of cells being associated with an identity number;

means for obtaining an identity number of the cell;

means for obtaining, based on the identity number, mapping relation indicating that the device either performs transmissions or performs measurement in the set of IMRs;

means for determining, from the set of IMRs and based on the identity number and the mapping relation, a transmission subset of IMRs in which the device performs transmissions; and

means for determining, from the set of IMRs and based on the identity number and the mapping relation, a measurement subset of IMRs in which the device measures interferences caused by the other cells.

13. The apparatus of claim 12, wherein seven identity numbers are reused for all cells in a network based on geometrical relation, seven IMRs are reused for all cells, and cells associated with the same identity number uses the same mapping relation.

14. The apparatus of claim 12 or 13, wherein the group of cells with different seven identity numbers use seven different mapping relations to configure seven different IMRs, respectively, such that each cell performs transmission in 3 different IMRs, 3 different cells performs transmission in each IMR, and any two distinct cells performs one concurrent transmission in seven IMRs.

15. The apparatus of any one of claims 12, 13 or 14, wherein a liner system is constructed by the device to estimate unknown interferences based on measurements in the measurement subset.

16. The apparatus of claim 12 or 15, wherein means for measuring interferences comprises:

means for estimating, based on the measured interferences, an interference caused by each cell in the group;

means for determining a cell with a strongest interference power based on the estimation; and

means for causing transmission power of the determined cell to be reduced.

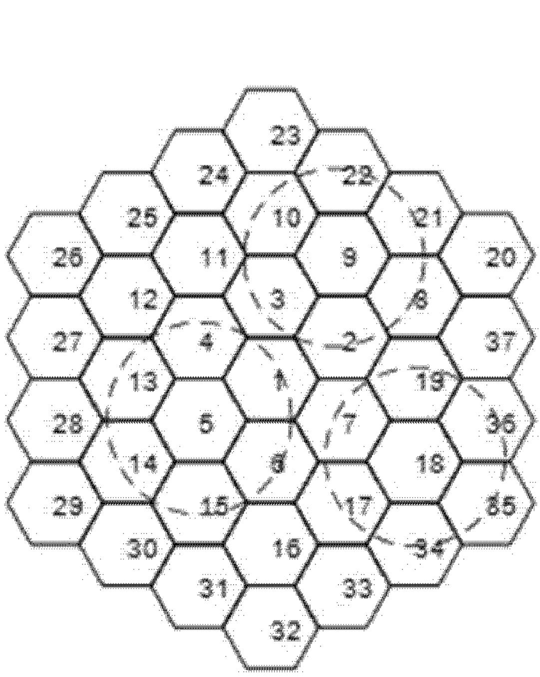
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FIG. 1A

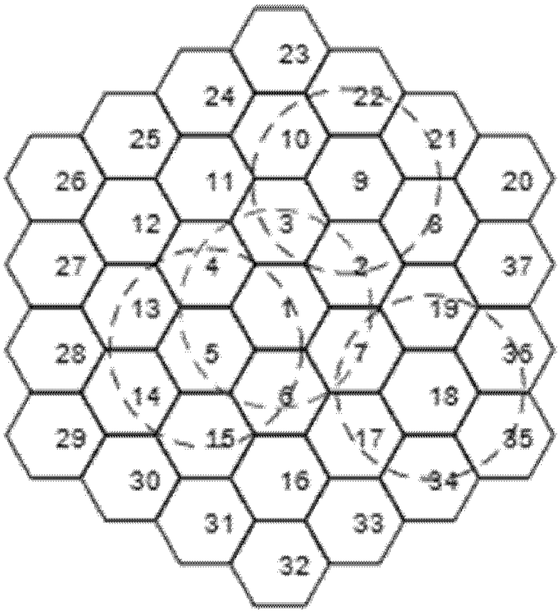
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FIG. 1B

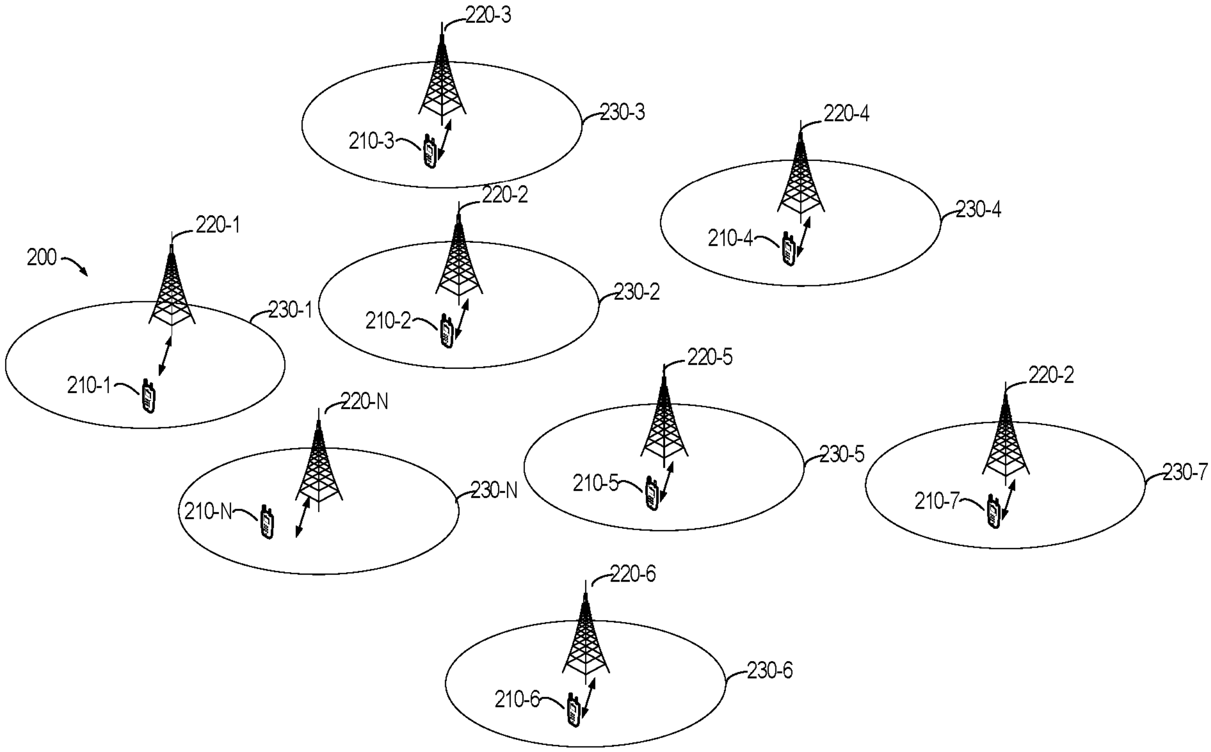
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FIG. 2

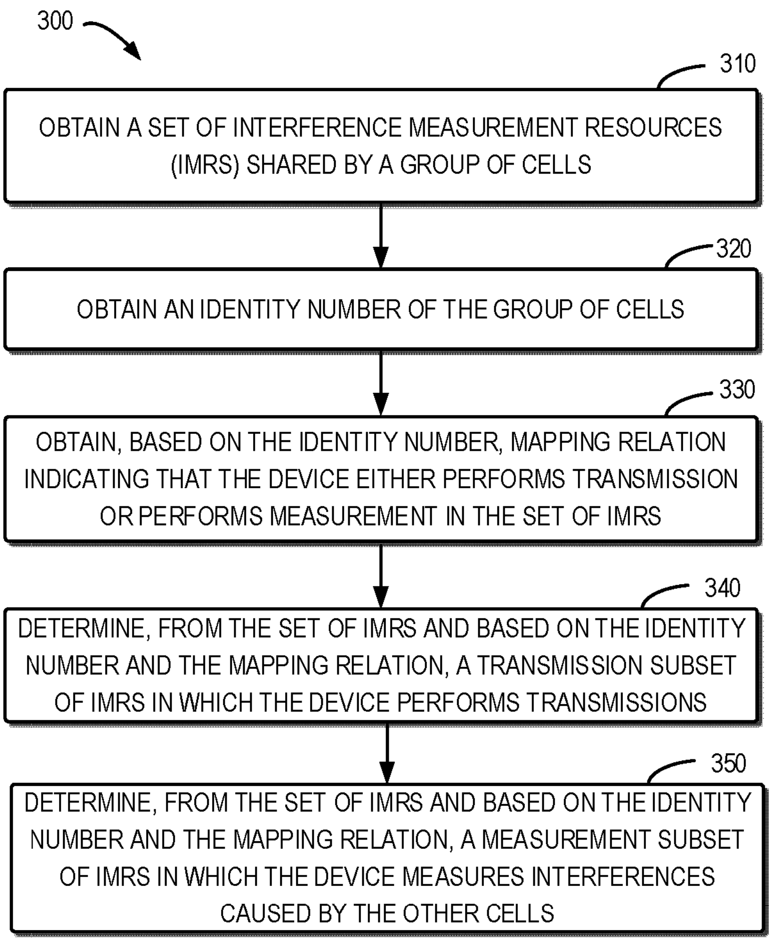
300
310
OBTAIN A SET OF INTERFERENCE MEASUREMENT RESOURCES (IMRS) SHARED BY A GROUP OF CELLS
320
OBTAIN AN IDENTITY NUMBER OF THE GROUP OF CELLS
330
OBTAIN, BASED ON THE IDENTITY NUMBER, MAPPING RELATION INDICATING THAT THE DEVICE EITHER PERFORMS TRANSMISSION OR PERFORMS MEASUREMENT IN THE SET OF IMRS
340
DETERMINE, FROM THE SET OF IMRS AND BASED ON THE IDENTITY NUMBER AND THE MAPPING RELATION, A TRANSMISSION SUBSET OF IMRS IN WHICH THE DEVICE PERFORMS TRANSMISSIONS
350
DETERMINE, FROM THE SET OF IMRS AND BASED ON THE IDENTITY NUMBER AND THE MAPPING RELATION, A MEASUREMENT SUBSET OF IMRS IN WHICH THE DEVICE MEASURES INTERFERENCES CAUSED BY THE OTHER CELLS

FIG. 3

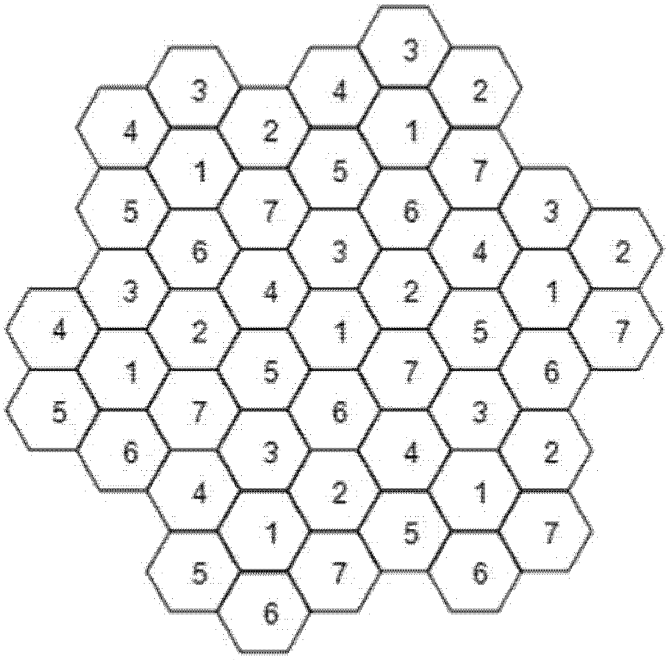

FIG. 4

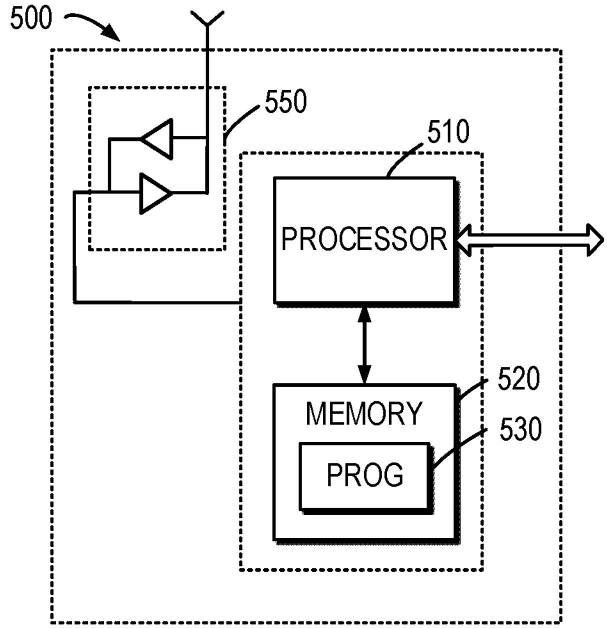

FIG. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2018/105503

A. CLASSIFICATION OF SUBJECT MATTER

H04L 5/00(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI, EPODOC, CNPAT, CNKI, IEEE: IMR cell identity number measurement

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CN 108418667 A (HUAWEI TECHNOLOGIES CO., LTD.) 17 August 2018 (2018-08-17) the abstract, description, paragraphs [0094]-[0100]	1-16
A	US 2017180194 A1 (SAMSUNG ELECTRONICS CO., LTD.) 22 June 2017 (2017-06-22) the whole document	1-16
A	WO 2014067074 A1 (HUAWEI TECHNOLOGIES CO., LTD.) 08 May 2014 (2014-05-08) the whole document	1-16
A	CN 108353299 A (SONY CORPORATION) 31 July 2018 (2018-07-31) the whole document	1-16

☐ Further documents are listed in the continuation of Box C. ☑ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
30 May 2019	**12 June 2019**

Name and mailing address of the ISA/CN	Authorized officer
National Intellectual Property Administration, PRC 6, Xitucheng Rd., Jimen Bridge, Haidian District, Beijing 100088 China	**SUN,Fangtao**
Facsimile No. **(86-10)62019451**	Telephone No. **86-(10)-53961567**

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WO	2014067074	A1	08 May 2014	US	2018110034	A1	19 April 2018
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				CN	108494536	A	04 September 2018
				US	9867176	B2	09 January 2018
				CN	104081846	A	01 October 2014
				CN	104081846	B	06 March 2018
				EP	2903370	B1	21 February 2018
				RU	2604639	C1	10 December 2016
				EP	2903370	A4	23 September 2015
				EP	3361805	A1	15 August 2018
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				KR	20180081049	A	13 July 2018
				JP	WO2017077753	A1	16 August 2018
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