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Dimou et al.

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(54) **METHODS AND DEVICES FOR REDUCING INTERFERENCE IN HETEROGENEOUS COMMUNICATION NETWORKS BASED ON INTER-CELL INTERFERENCE COORDINATION**

(71) Applicant: **Telefonaktiebolaget L M Ericsson (publ)**, Stockholm (SE)

(72) Inventors: **Konstantinos Dimou**, Stockholm (SE); **Asif Ali Khan**, Stockholm (SE)

(73) Assignee: **TELEFONAKTIEBOLAGET L M ERICSSON (PUBL)**, Stockholm (SE)

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USPC 455/448–451, 452.1, 452.2, 454, 500, 455/501, 230, 231; 370/329
See application file for complete search history.

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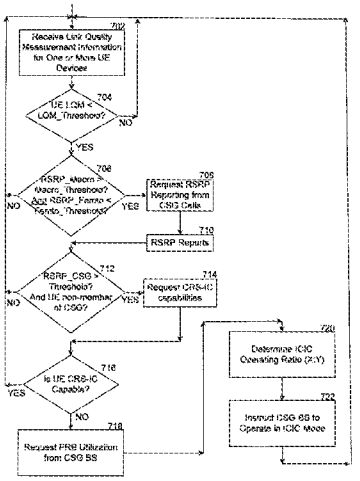
Primary Examiner — Magdi Elhag
(74) *Attorney, Agent, or Firm* — Rothwell, Figg, Ernst & Manbeck, P.C.

(57) **ABSTRACT**

Devices and methods for reducing interference in a communication network including a first node and a first node coverage area, a second closed subscriber group (CSG) node located within the first node coverage area, and one or more user equipment (UE) devices located within the first node coverage area are provided. In one embodiment, a method includes receiving link quality measurement information from the one or more UE devices and determining if a link quality value for a UE device is below a predetermined link quality threshold value and is caused by the second CSG node. If both conditions are true, if the UE device is a member of the second CSG node, and if the first UE device does not include interference cancellation capability, the method further includes instructing the second CSG node to mute transmission causing interference for the UE device.

24 Claims, 12 Drawing Sheets



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H04W 36/30 (2009.01)
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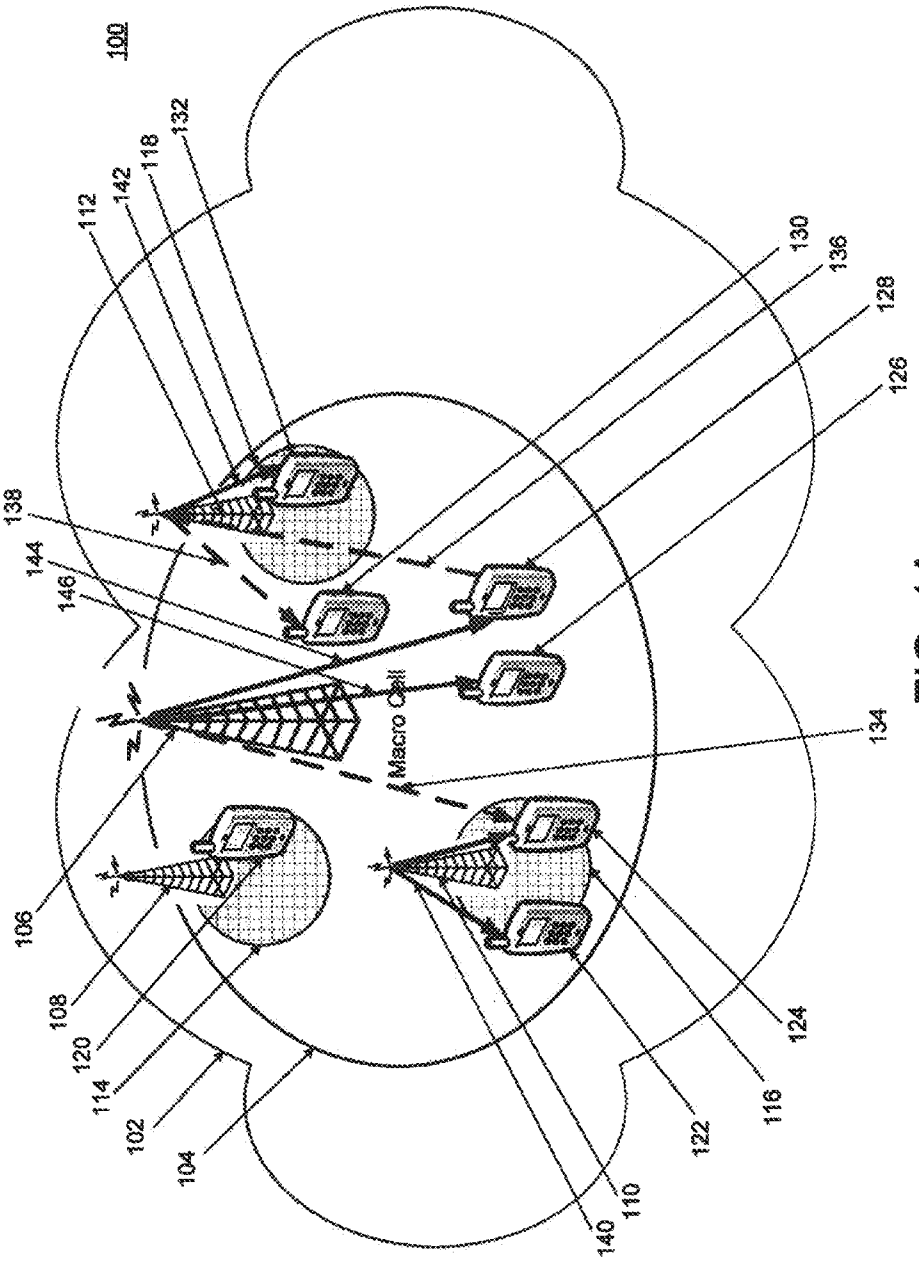

100
132
118
142
112
130
136
128
126
138
144
146
Macro Cell
134
106
108
120
114
102
104
140
110
122
116
124

FIG. 1A

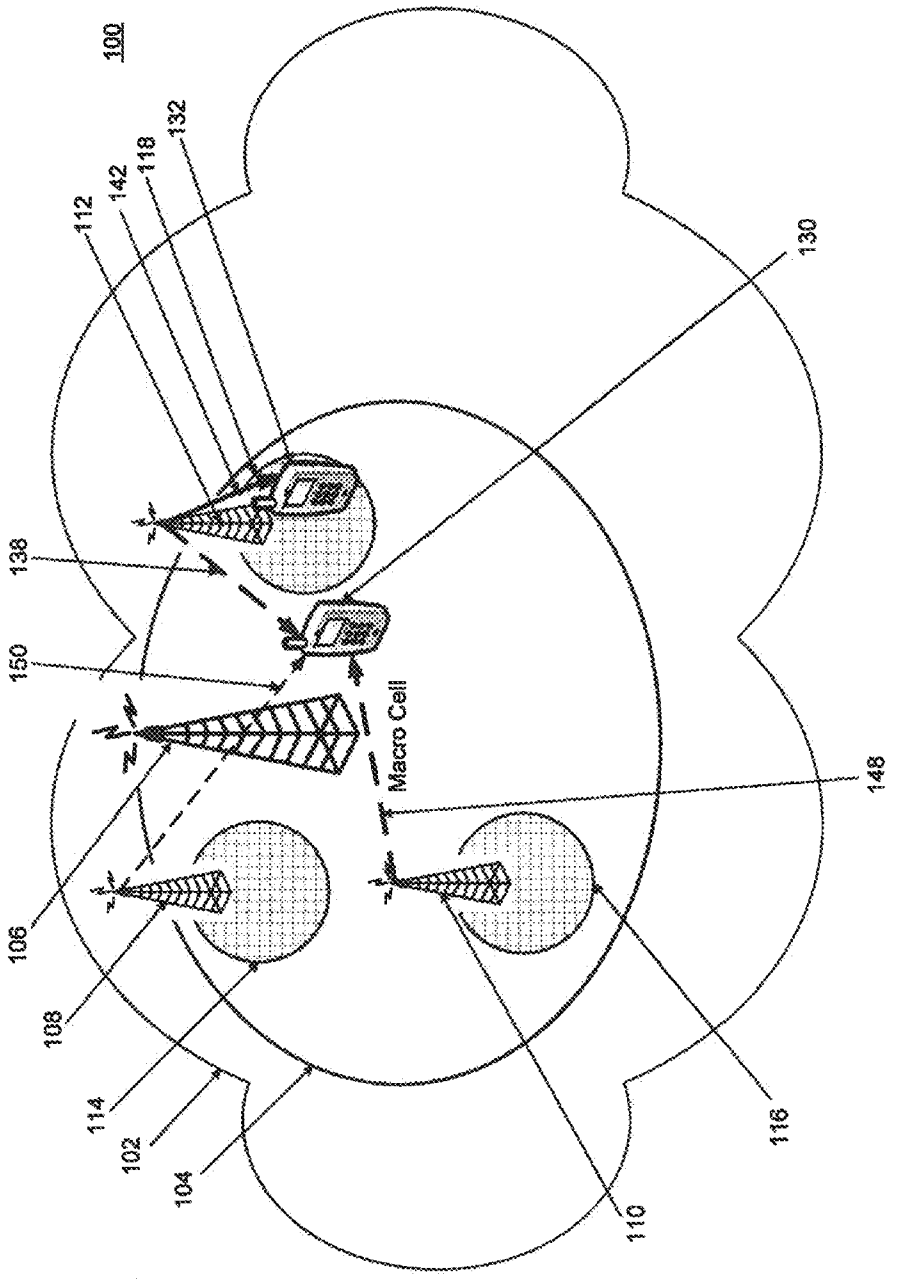

100
132
118
142
112
130
138
150
Macro Cell
148
106
108
114
102
104
110
116

FIG. 1B

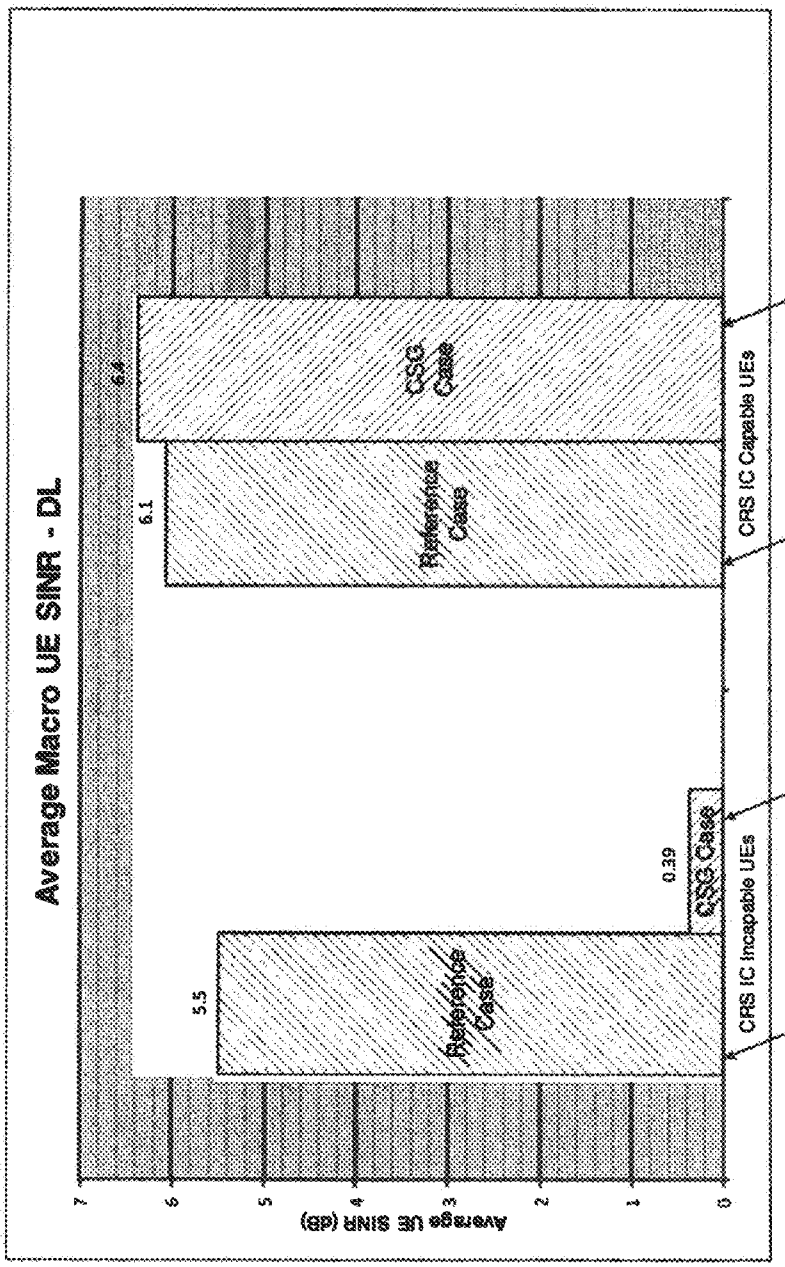

Average Macro UE SINR - DL
Average UE SINR (dB)
0
1
2
3
4
5
6
7
5.5
Reference Case
0.39
CSG Case
CRS IC Incapable UEs
202
204
6.1
Reference Case
6.4
CSG Case
CRS IC Capable UEs
206
208

FIG. 2

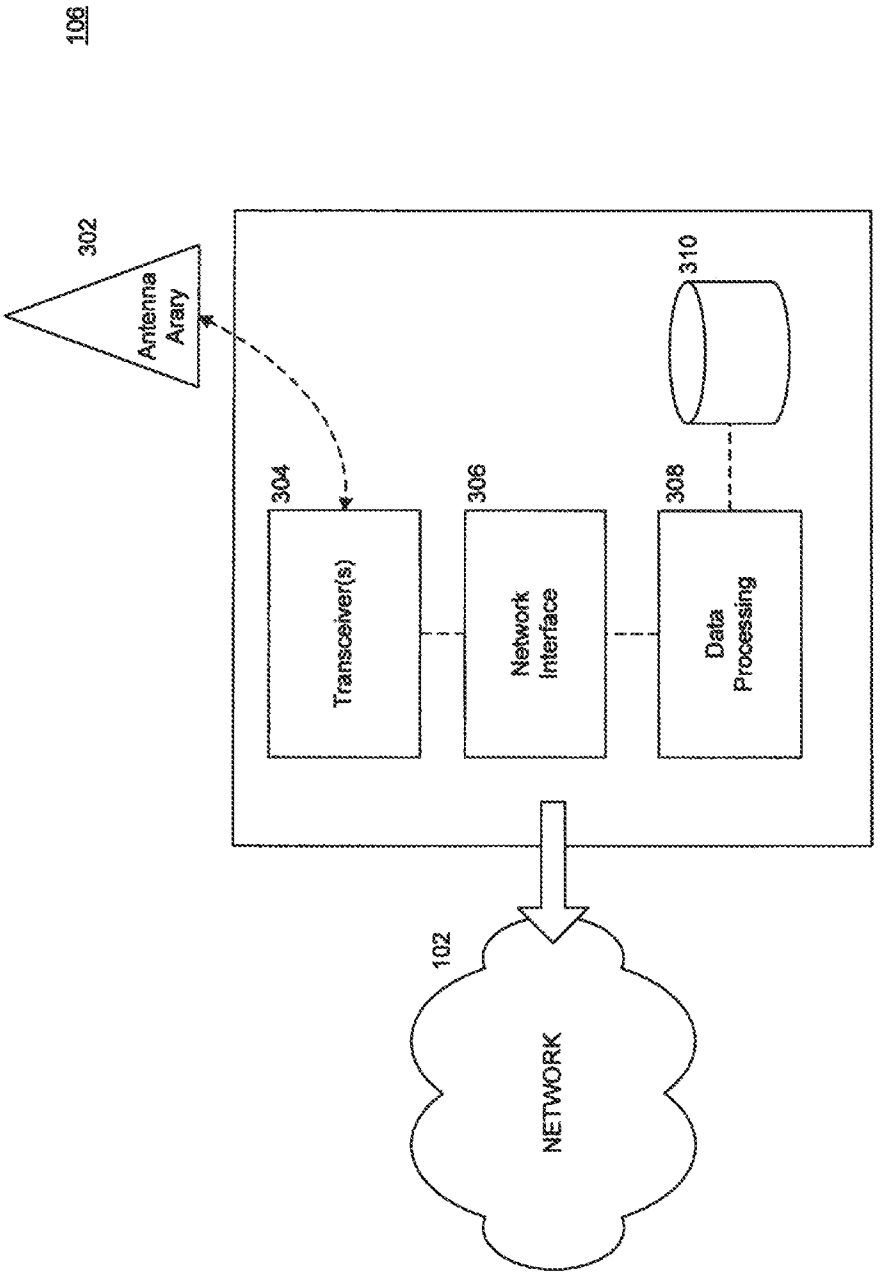

106
302
Antenna Array
310
304
306
308
Transceiver(s)
Network Interface
Data Processing
102
NETWORK

FIG. 3

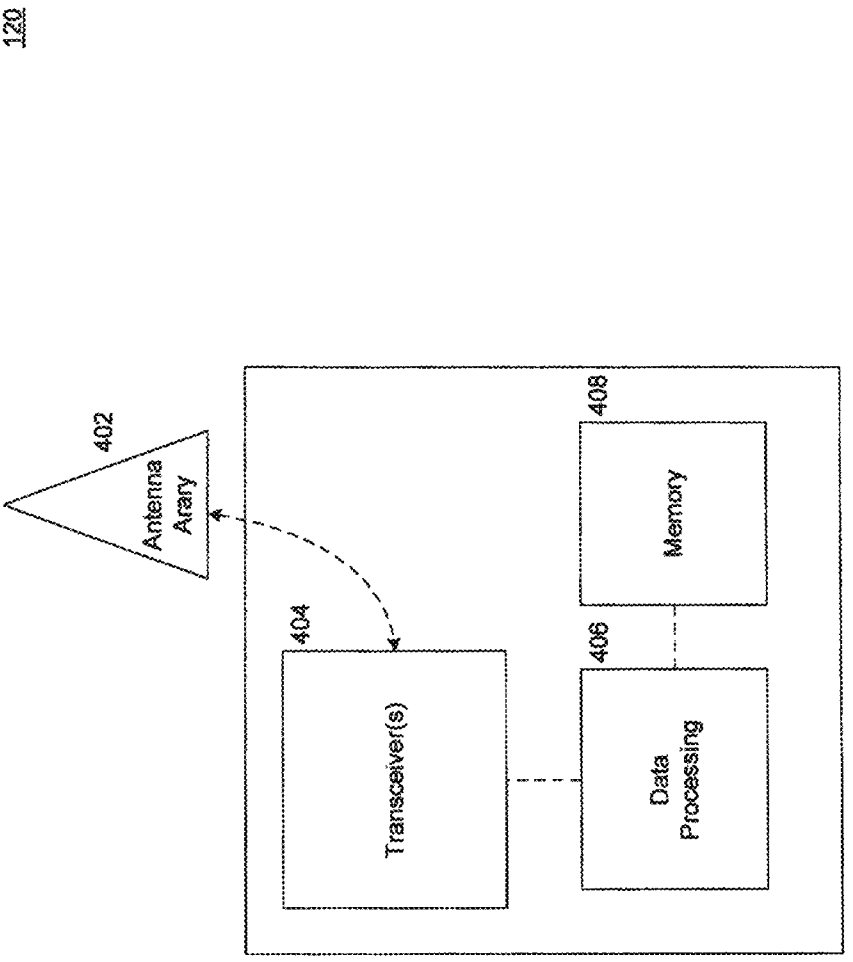

120
402
Antenna Array
404
Transceiver(s)
406
Data Processing
408
Memory

FIG. 4

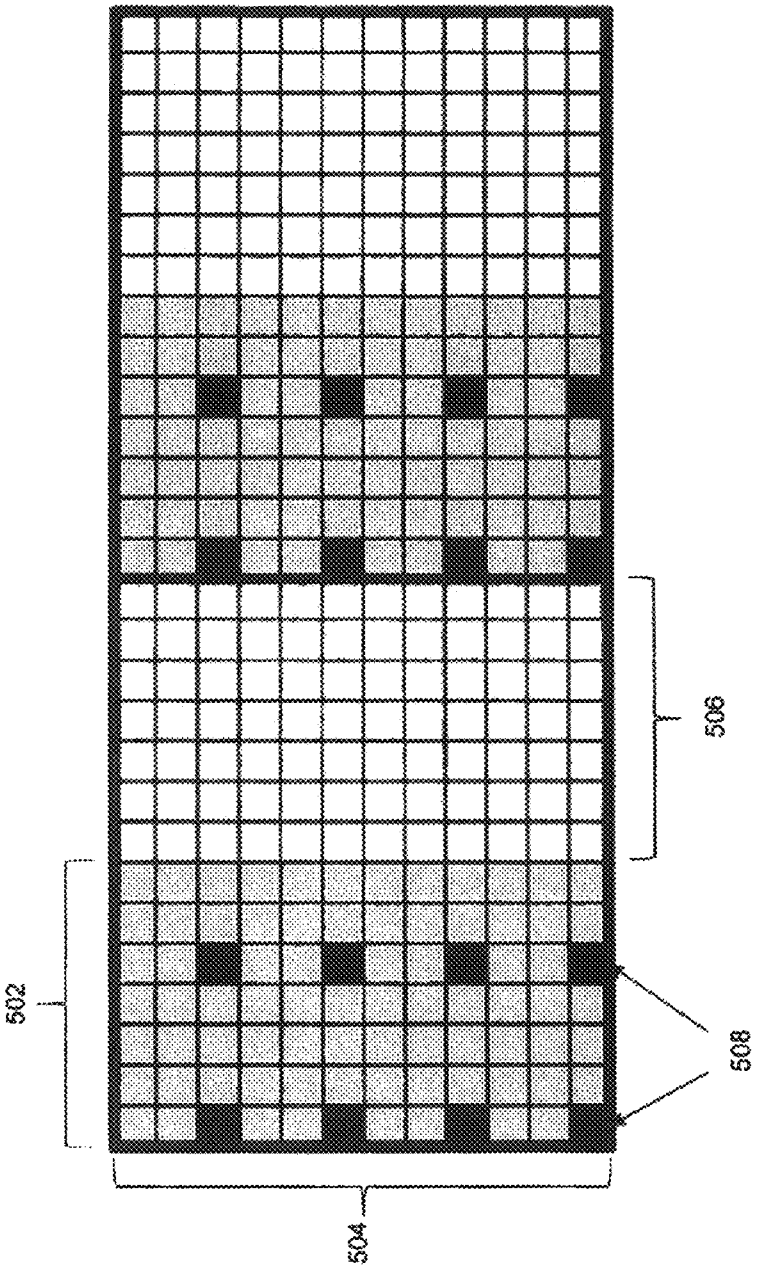


FIG. 5

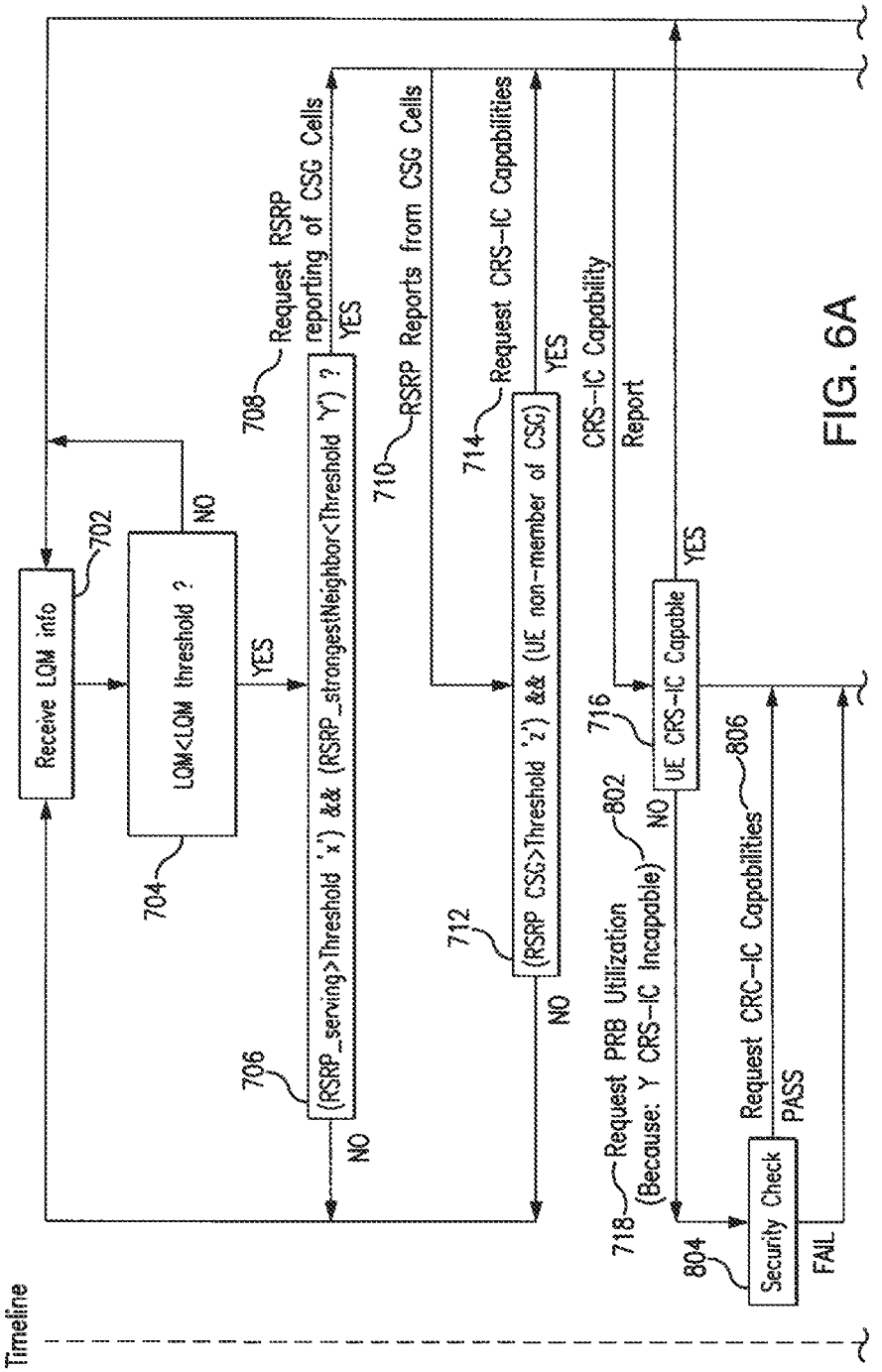

Timeline
Receive LQM info
702
LQM<LQM threshold ?
704
NO
YES
(RSRP_serving>Threshold 'x') && (RSRP_strongestNeighbor<Threshold 'Y') ?
706
NO
YES
708
Request RSRP reporting of CSG Cells
RSRP Reports from CSG Cells
710
(RSRP CSG>Threshold '2') && (UE non-member of CSG)
712
NO
YES
714
Request CRS-IC Capabilities
CRS-IC Capability Report
716
UE CRS-IC Capable
NO
YES
Request PRB Utilization (Because: Y CRS-IC Incapable)
718
802
Request CRC-IC Capabilities
806
Security Check
804
PASS
FAIL

FIG. 6A

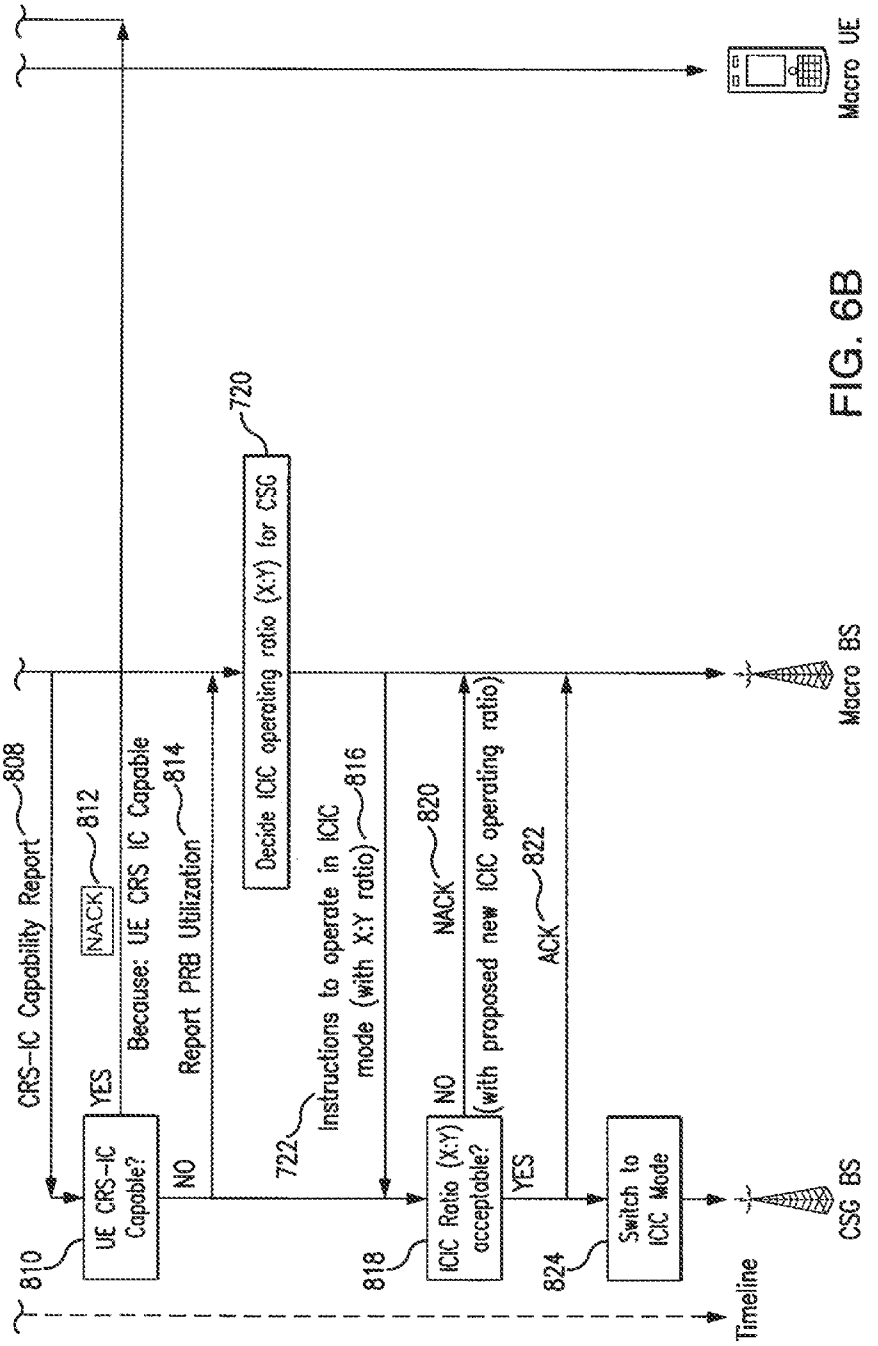

Macro UE
Macro BS
CSG BS
Timeline
810
CRS-IC Capability Report
808
UE CRS-IC Capable?
NACK
812
YES
Because: UE CRS IC Capable
NO
Report PRB Utilization
814
Decide ICIC operating ratio (X:Y) for CSG
720
722
Instructions to operate in ICIC mode (with X:Y ratio)
816
818
ICIC Ratio (X:Y) acceptable?
NO
NACK
820
(with proposed new ICIC operating ratio)
YES
ACK
822
824
Switch to ICIC Mode

FIG. 6B

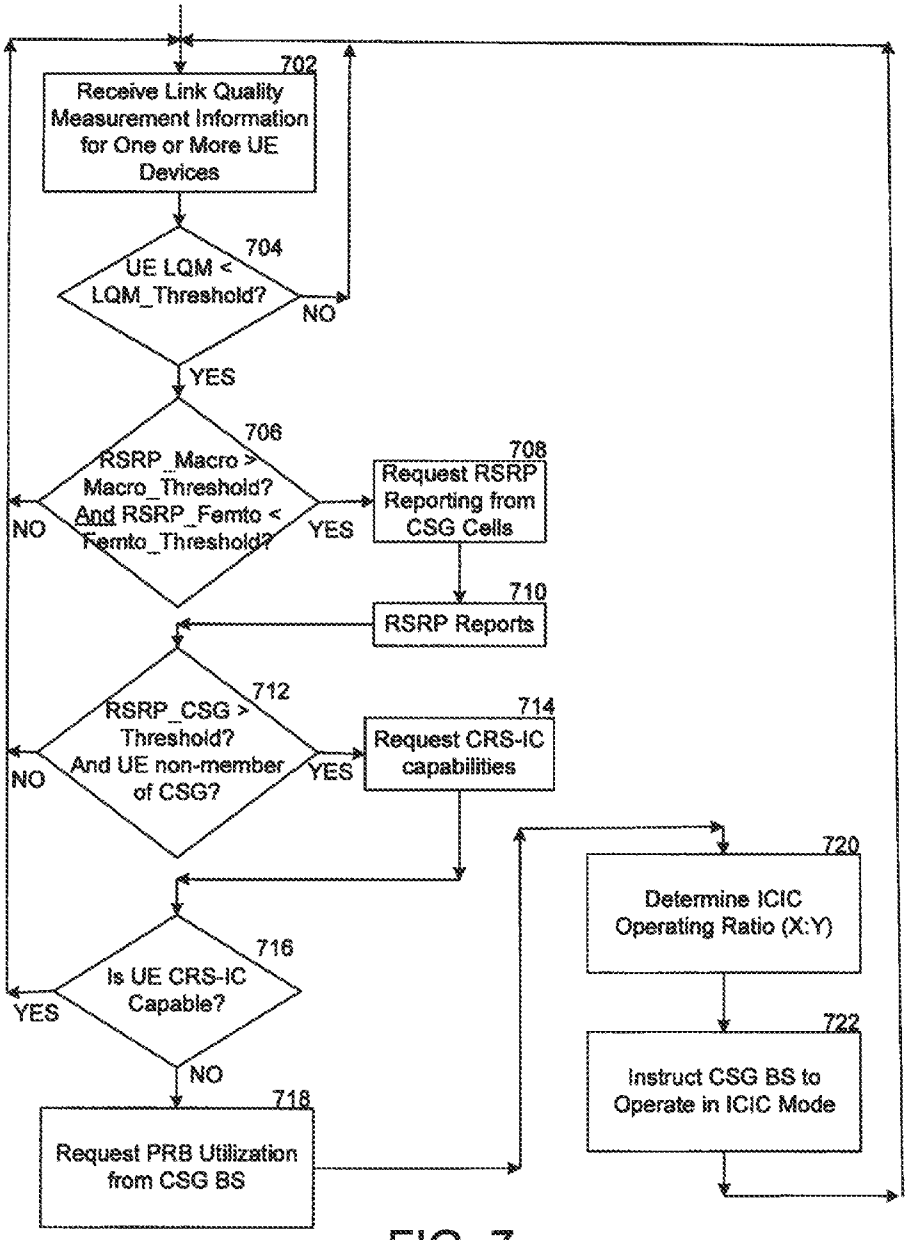

702
Receive Link Quality Measurement Information for One or More UE Devices
704
UE LQM < LQM_Threshold?
NO
YES
706
RSRP_Macro > Macro_Threshold? And RSRP_Femto < Femto_Threshold?
NO
YES
708
Request RSRP Reporting from CSG Cells
710
RSRP Reports
712
RSRP_CSG > Threshold? And UE non-member of CSG?
NO
YES
714
Request CRS-IC capabilities
716
Is UE CRS-IC Capable?
YES
NO
718
Request PRB Utilization from CSG BS
720
Determine ICIC Operating Ratio (X:Y)
722
Instruct CSG BS to Operate in ICIC Mode

FIG. 7

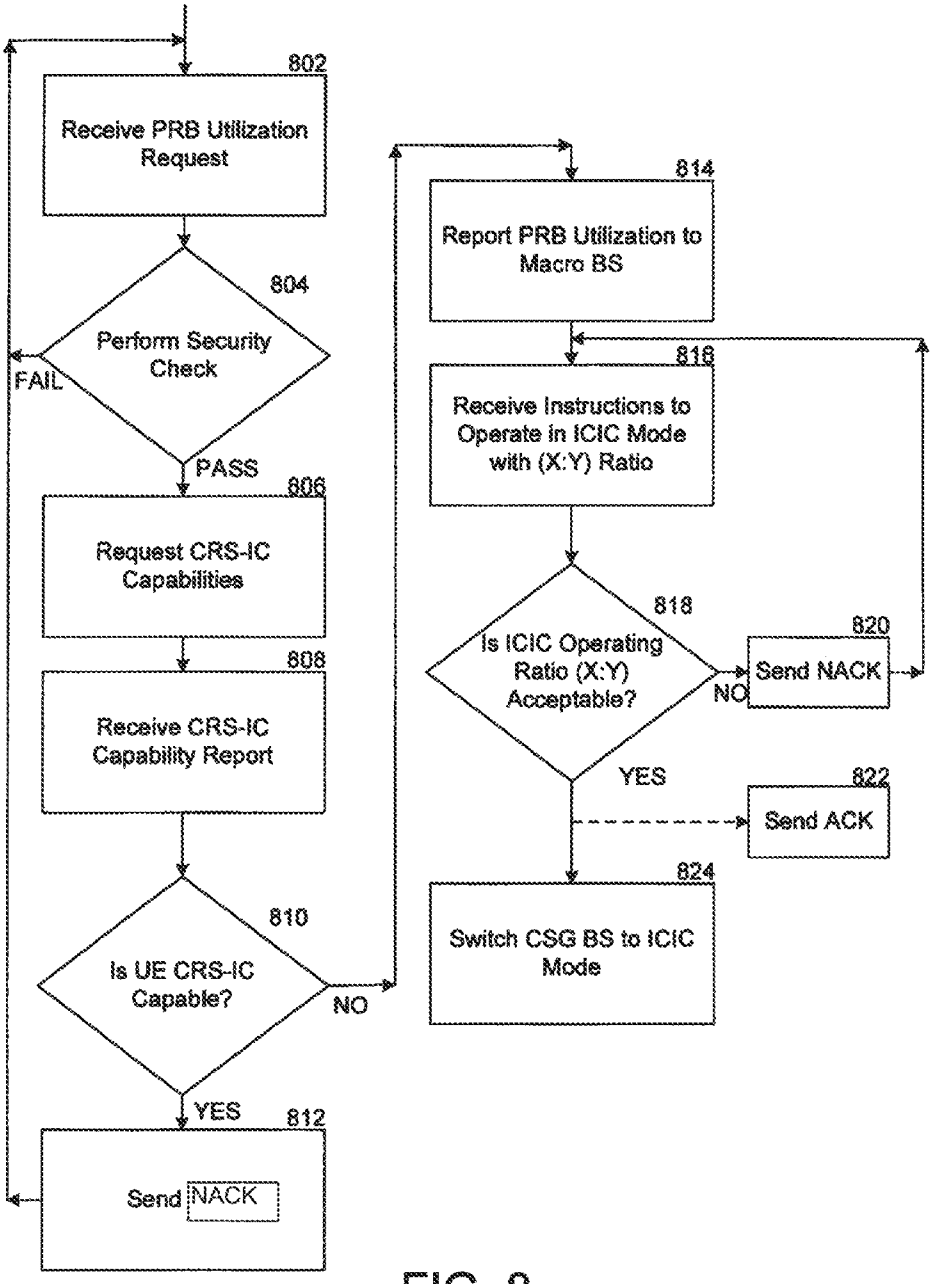

802
Receive PRB Utilization Request
804
Perform Security Check
FAIL
PASS
806
Request CRS-IC Capabilities
808
Receive CRS-IC Capability Report
810
Is UE CRS-IC Capable?
NO
YES
812
Send NACK
814
Report PRB Utilization to Macro BS
816
Receive Instructions to Operate in ICIC Mode with (X:Y) Ratio
818
Is ICIC Operating Ratio (X:Y) Acceptable?
NO
820
Send NACK
YES
822
Send ACK
824
Switch CSG BS to ICIC Mode

FIG. 8

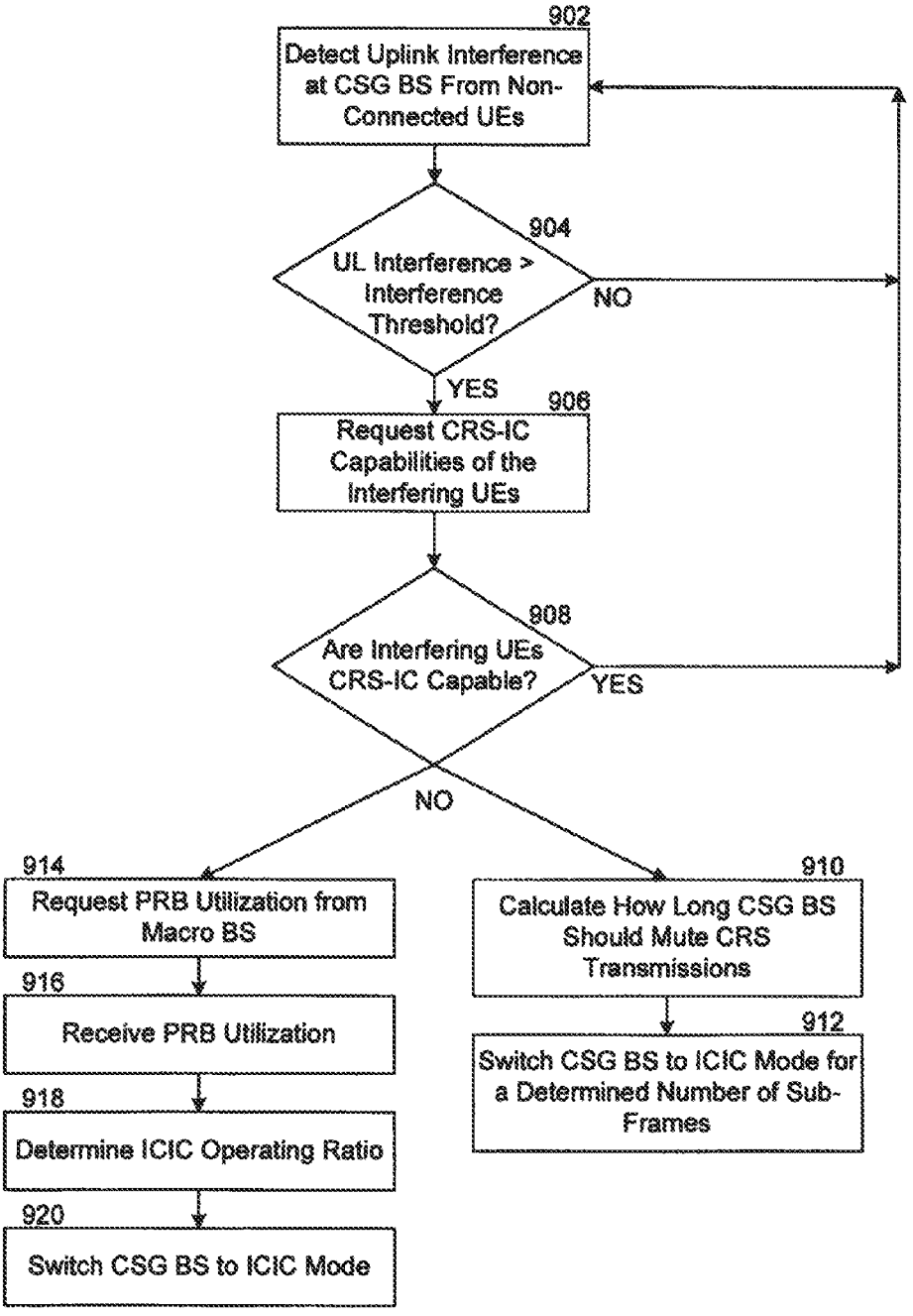

902
Detect Uplink Interference at CSG BS From Non-Connected UEs
904
UL Interference > Interference Threshold?
NO
YES
906
Request CRS-IC Capabilities of the Interfering UEs
908
Are Interfering UEs CRS-IC Capable?
YES
NO
914
Request PRB Utilization from Macro BS
916
Receive PRB Utilization
918
Determine ICIC Operating Ratio
920
Switch CSG BS to ICIC Mode
910
Calculate How Long CSG BS Should Mute CRS Transmissions
912
Switch CSG BS to ICIC Mode for a Determined Number of Sub-Frames

FIG. 9

FIG. 10A

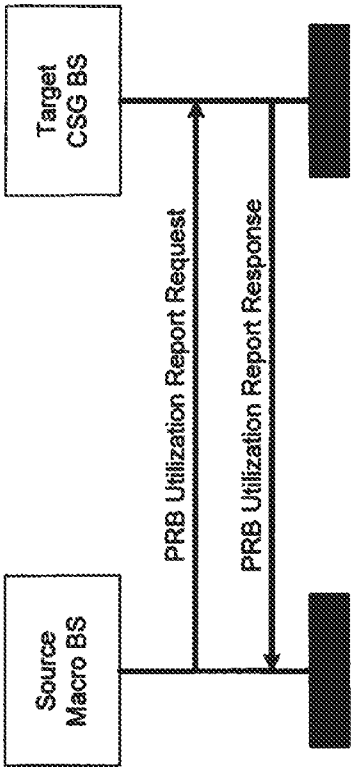
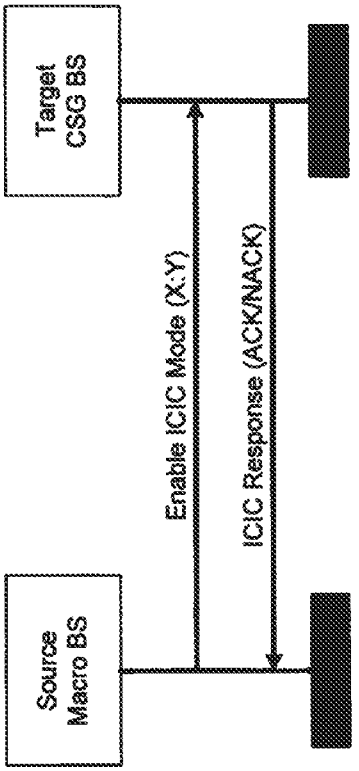


FIG. 10B



METHODS AND DEVICES FOR REDUCING INTERFERENCE IN HETEROGENEOUS COMMUNICATION NETWORKS BASED ON INTER-CELL INTERFERENCE COORDINATION

TECHNICAL FIELD

The present invention relates generally to improving data transmission in communication networks, and more particularly, to methods and devices for reducing interference in heterogeneous communication networks based on inter-cell interference coordination.

BACKGROUND

Currently, the deployment of heterogeneous networks (HetNets) is viewed as one of the most cost efficient deployment strategies for wireless communication systems in addressing the growing traffic demands and the expectation for higher data rates. Typical cellular networks today are characterized by non-uniform user and traffic distributions. HetNets complement the macro networks with low power nodes (LPNs) of a diverse nature, such as micro, pico, and femto base stations or relay nodes, which can achieve significantly improved capacity and high data rates. The resulting fragmented multi-layer architecture HetNet is illustrated in FIG. **1**A, showing a macro cell **104** as part of a communication network **102**, with a first node, or base station **106**, and with second node LPNs, or base stations, **108-112**.

In heterogeneous networks, there are various types of base stations, each of which can be associated with differing cell sizes. For instance, large base stations, such as macro cell base stations **106**, are typically installed on masts, rooftops and other existing structures. Macro cell base stations **106** normally have power outputs on the order of tens of watts and, thus, provide large cell coverage. Small base stations, such as micro, pico and femto cell base stations **108-112** are LPNs, which are commonly designed for residential or small business environments. The power outputs for these small base stations **108-112** are normally less than a watt to a few watts, which results in a small cell coverage range.

HetNets are less susceptible to the strains on signal power (due to the increase in distance from the transmitting point) and are well known to defy the inverse square law of distance by moving the Base Station (BS) closer to users and providing similar Quality-of-Service (QoS) throughout the cell area. Thus, HetNet deployments possess an inherent capability to address the limitations implied by channel capacity and to provide a uniform user experience throughout the cell area, irrespective of user location. The potential of HetNets to bring gains in coverage and capacity are accomplished because:

- Moving the BS closer to users results in better radio link conditions, which in turn leads to higher data rates for users connected to the low power nodes **108-112**.
- LPN cells **114-118** provide access to the users previously handled by the macro layer, thus reducing the load from the macro cell **104** (called "macro offloading"). This results in higher availability of resources and thus higher data rates for the users connected to macro base stations **106**.
- HetNet deployments generally tend to provide uniform data rates within a given area **104**.

Within 3GPP Long Term Evolution Advanced (LTE-A), three types of LPNs are specified within the 3GPP TR 36.814 specification standard according to their respective access rights. Open Access (OA) LPNs provide that any User Equipment (UE) **120**, **122**, **124**, and **132** can associate with the Open Access LPN if the LPN cell is the one providing the best signal quality to the UE. As used herein, the terms LPN and LPN cell represent any type of small range, or low power, cell—e.g., micro, pico or femto cells **114-118**. The terms LPN, micro, pico and femto cells are used interchangeably herein. Closed Subscriber Group (CSG) LPNs **108-112** provide additional privacy to the user as control is granted to the end user by letting the cell owner authorize access to the LPN **108-112** and configure the set of UEs **120**, **122**, **124**, and **132** to be provided service by the LPN **108-112**, called authorized UEs. Thus, the cell owner selects a set of UEs and configures the CSG LPN to limit access only to them. Hybrid Access (HA) LPNs are a composite of OA and CSG modes; which by default operate in CSG mode while switching into OA mode at certain instances, thus providing service to certain non-authorized UEs temporarily, e.g., visitors within a given home, etc.

The access nature of the LPNs **108-112** has different implications on system performance based on the tradeoff between interference and increased capacity. The incorporation of LPNs **108-112** within the macro cell **104** can cause interference to the macro UEs **126-130** that are in close proximity to the LPNs **108-112** but are associated with the macro cell **104**. OA tends to provide higher gains in system capacity and increase UE throughput, while causing less interference to the nearby UEs. However, the presence of CSG-type LPNs **108-112** within the macro cell **104** have a tendency to accentuate the interference scenarios and to enhance the cell edge effect in the macro cell area. As the CSG cells **114-118** provide access only to a limited number of UEs **120**, **122**, **124**, and **132**, the nearby macro UEs **126-130** experience severe interference from the CSG cells **114-118**. In particular, the presence of CSG cells **114-118** causes significant interference problems for the macro UEs **126-130** and results in very low Signal to Interference-plus-Noise Ratio (SINR), UE throughput, and a reduced system capacity.

The presence of CSG cells **114-118** intensifies the serving conditions in the macro cell area **104** and, as a result, more UEs experience service outages. The prime reason for the cause of degraded system performance for the CSG scenarios is the interference resulting due to limited service provisioning constraints of the CSG cells **114-118**. As the CSG cells **114-118** only provide access to a limited number of UEs (called authorized UEs) **120**, **120**, **124**, and **132**, the unauthorized macro UEs **126-130** undergo severe interference from the CSG transmission, which results in reduced performance, but cannot access the CSG cell **114-118** despite the relative proximity of the CSG base station **108-112**. By contrast, in OA scenarios, if a UE is operating close enough to an OA base station to experience significant interference from the OA base station, the UE will typically be able to access the corresponding OA cell and use the OA base station as its serving base station.

FIG. **1**B illustrates major interference scenarios that can be observed in a HetNet deployment. For example, the downlink transmission signals **138** and **148** from the CSG LPNs **112** and **110** to the macro UE **130** causes interference between the macro UE **130** and its macro BS **106**. Further, with respect to the uplink (UL) transmission signals, macro UEs associated with the macro cell, when located close to a CSG cell, cause high UL interference for the UEs connected to the CSG cell and transmitting in the UL.

CSG cells **114-118** have high tendencies to impact the performance of nearby UEs **126-130** that are connected to the macro cell **104**. A major source of interference in HetNet deployments featuring CSG cells is the transmission of Cell-

specific Reference Signals (CRS) from the CSG cells. FIG. **2** illustrates the exemplary downlink SINR of macro UEs for different UE types. The Reference Case refers to a macro only scenario without any CSG LPN cells in the macro cell area **104**, and the CSG Case refers to the situation where there are, for example, ten CSG LPNs in the macro cell. Further, for example, 20% of the UEs in the macro cell are connected to the CSG cells. Under this scenario, as shown in FIG. **2**, if the UEs are not capable of cancelling interference resulting from the CRS signals, the average SINR of the macro UEs is observed to suffer significant reduction. For example, as shown in column **204**, the SINR for the macro UEs that lack CRS interference cancellation (IC) capability is 0.39 dB. In contrast, if the macro UEs are capable of cancelling CRS signal interference, the CSG cells tend to improve the SINR of the UEs by offloading the macro cell, as shown in column **206** with the SINR of 6.4 dB. This indicates that a major part of interference in CSG-featured HetNet deployments is caused due to the transmission of CRS signals from the CSG BSs. Since these CSG cells provide service to a limited number of UEs, the Physical Resource Block (PRB) utilization in these cells is very small (e.g., typically less than 10%, even for a heavily loaded traffic scenario), and thus the transmission on the Physical Downlink Shared Channel (PDSCH) is less frequent. Hence, the interference is mainly caused by the CRS signals which are transmitted (in each sub-frame) by all BS in the downlink (DL).

Since the CRS interference cancellation is a relatively new concept to be introduced in UEs of Rel-11, the UEs of previous releases lack this functionality. Thus, for HetNet deployments featuring CSG cells, there is a need to devise and implement efficient Inter-Cell Interference Coordination (ICIC) techniques to limit the negative performance impact on macro UEs under the influence of interference from the CSG cells.

The current techniques aiming to overcome the problem of interference due to the transmission of neighboring cells' CRS can be characterized into Network Assisted (NA) or UE-Implemented (UE-I) solutions. In the NA solutions, static or semi-static (pre-settled policy, triggered by an event) procedures are implemented among the BSs to perform ICIC. In contrast, the UE-Implemented procedures mainly advocate the cancellation of interference due to CRS at the UE.

One NA technique is Enhanced Inter-Cell Interference Coordination (e-ICIC) using Almost Blank Sub-frames (ABS). The ABS technique controls the macro cell, the LPNs, or both to limit the muting of transmissions at distinct intervals to avoid interference. The macro cells mute their transmissions in alternate sub-frames to protect the UEs associated with the pico cells from the interference caused by the macro. However, to perform channel measurements and to maintain compatibility among the UEs of different releases, CRS signals are transmitted in all sub-frames (including the muted sub-frames). This technique may be useful for deployments featuring OA cells, where the interference experienced by the UEs is dominated by the transmissions on the Physical Downlink Shared Channel (PDSCH). However, for the circumstances where CSG cells are deployed in the system, muting of the macro cell or the CSG cells is not an acceptable solution since most of the traffic (such as more than 95%) in such a scenario is being served by the macro cell (i.e. high macro PRB utilization). This means that muting transmissions of the macro BS is not desirable because it will result in excessive scheduling delays and lead to congestion in the macro cell. Further, muting transmissions of the CSG cells does not reduce the DL interference to macro UEs, since the interference is mainly caused by the transmission of CRS, and in the ABS technique, CRS are transmitted in all sub-frames (even in the muted ones).

A UE-Implemented technique is known as Cell-specific Reference Signals-Interference Cancellation (CRS-IC). CRS-IC is an Interference Cancellation (IC) mechanism implemented in the UE with the goal of minimizing the interference from CRS with use of appropriate signal processing. As the CRSs are transmitted on pre-determined intervals with a well determined format, the UEs can reliably estimate, or obtain these signals from neighbor cells, and thus can perform the interference cancellation without the need for any strict coordination mechanisms between cells. However, implementing CRS-IC within UEs in general is a complicated task which increases the device cost and results in increased UE energy consumption. Furthermore, removing the interfering signals from each transmission takes away part of the useful signal, resulting in low SINR. Moreover, cancellation of interference from the CRS under CRS-IC is problematic due to estimation errors. Further, since CRS-IC is a relatively new concept to be introduced in UEs of Rel-11, the UEs of previous releases lack this functionality.

Accordingly, there is a need to reduce interference in UEs that may be caused by data and/or reference signals from, for example, UE devices connected to a neighbor cell in a HetNet deployment featuring CSG cells.

SUMMARY

Particular embodiments are directed to devices and methods for reducing interference in heterogeneous communication networks based on inter-cell interference coordination.

In one particular embodiment, a method is provided for reducing interference in a communication network including a first node and a first node coverage area, a second closed subscriber group (CSG) node, transmitting on a bandwidth at a lower power than the first node and located within the first node coverage area, and one or more user equipment (UE) devices located within the first node coverage area. The method includes receiving link quality measurement (LQM) information from the one or more UE devices and determining, based on the received link quality measurement information, if a link quality value for a first UE device of the one or more UE devices is below a predetermined link quality threshold value. If the link quality value is below the predetermined link quality threshold value, the method further includes determining, based on the received link quality measurement information, if the link quality value degradation is caused by the second CSG node. If the link quality value degradation is caused by the second CSG node, the method further includes determining if the first UE device is a member of the second CSG node and, if not a member, the method further includes determining if the first UE device includes an interference cancellation (IC) capability and, if the first UE device does not include an IC capability, the method further includes instructing the second CSG node to operate in an IC mode that mutes transmission of the second CSG node on a part of the bandwidth causing interference for the first UE device. The method further includes, if the first UE device does not include an IC capability, initiating a handshake between the first node and the second CSG node to identify a part of bandwidth for muting transmission and instructing the second CSG node to operate in an IC mode that mutes transmission of data and/or reference signals causing interference for the first UE device on the identified part of the bandwidth.

According to particular embodiments, the method further includes, after determining if the first UE device includes an

interference cancellation (IC) capability and prior to instructing the second CSG node to operate in an IC mode, requesting Physical Resource Block (PRB) utilization information for the second CSG node, receiving the PRB utilization information for the second CSG node, and determining, based on the received PRB utilization information, an ICIC operating ratio, wherein instructing the second CSG node causes the second CSG node to operate in an IC mode based on the ICIC operating ratio.

Certain embodiments are directed to a first node operable to reduce interference in a communication network including a first node coverage area, a second closed subscriber group (CSG) node, transmitting on a bandwidth at a lower power than the first node and located within the first node coverage area, and one or more user equipment (UE) devices located within the first node coverage area. The first node includes a processor; a memory coupled to the processor, a transceiver coupled to the processor, and an antenna coupled to the transceiver configured to transmit and receive signals. The processor is configured to receive link quality measurement (LQM) information from the one or more UE devices and to determine, based on the received link quality measurement information, if a link quality value for a first UE device of the one or more UE devices is below a predetermined link quality threshold value. If the link quality value is below the predetermined link quality threshold value, the processor is further configured to determine, based on the received link quality measurement information, if the link quality value degradation is caused by the second CSG node. If the link quality value degradation is caused by the second CSG node, the processor is further configured to determine if the first UE device is a member of the second CSG node and, if not a member, the processor is further configured to determine if the first UE device includes an interference cancellation (IC) capability and, if the first UE device does not include an IC capability, the processor is further configured to instruct the second CSG node to operate in an IC mode that mutes transmission of the second CSG node on a part of the bandwidth causing interference for the first UE device. If the first UE device does not include an IC capability, the processor is further configured to initiate a handshake between the first node and the second CSG node to identify a part of bandwidth for muting transmission and to instruct the second CSG node to operate in an IC mode that mutes transmission of data and/or reference signals causing interference for the first UE device on the identified part of the bandwidth.

In particular embodiments, the node processor is further configured to instruct the second CSG node to send a list of UE devices that are members of the second CSG node, to receive, at the first node, the list of member UE devices, and to search the received list of member UE devices to determine if the first UE device is a member of the second CSG node.

Particular embodiments provide a method for reducing interference in a communication network including a first node and a first node coverage area, a second closed subscriber group (CSG) node, transmitting at a lower power than the first node and located within the first node coverage area, and one or more user equipment (UE) devices located within the first node coverage area. The method includes receiving, at the second CSG node, a request for Physical Resource Block (PRB) utilization from the first node, requesting, by the second CSG node, interference cancellation (IC) capability of the one or more UE devices, receiving an IC capability report from the first node for the one or more UE devices, and determining if the one or more UE devices is IC capable based on the received capability report. If any of the UE devices are not IC capable, the method further includes reporting the PRB utilization to the first node; receiving, from the first node, instructions for the second CSG node to operate in an interference cancellation (IC) mode with a (X:Y) operating ratio, and switching, at the second CSG node, to an IC mode that mutes transmission of reference signals causing interference for the UE devices.

In some embodiments, the method further includes determining if the received (X:Y) operating ratio is acceptable and, if the received (X:Y) operating ratio is acceptable, the method further includes operating in an interference cancellation (IC) mode with the received (X:Y) operating ratio.

In another particular embodiment, a closed subscriber group (CSG) node is provided for reducing interference in a communication network including a first node and a first node coverage area, and one or more user equipment (UE) devices located within the first node coverage area, the CSG node transmitting at a lower power than the first node and located within the first node coverage area. The CSG node includes a processor; a memory coupled to the processor, a transceiver coupled to the processor, and an antenna coupled to the transceiver configured to transmit and receive signals. The processor is configured to receive, at the CSG node, a request for Physical Resource Block (PRB) utilization from the first node, to request, by the CSG node, interference cancellation (IC) capability of the one or more UE devices, to receive a IC capability report from the first node for the one or more UE devices, and to determine if the one or more UE devices is IC capable based on the received capability report. If any of the UE devices are not IC capable, the processor is further configured to report the PRB utilization to the first node, to receive, from the first node, instructions for the CSG node to operate in an interference cancellation (IC) mode with a (X:Y) operating ratio, and switch, at the CSG node, to an IC mode that mutes transmission of reference signals causing interference for the UE devices.

Some embodiments further provide for the processor being further configured to determine if the received (X:Y) operating ratio is acceptable and, if the received (X:Y) operating ratio is acceptable, the processor is further configured to operate the CSG node in an interference cancellation (IC) mode with the received (X:Y) operating ratio.

In another particular embodiment, a method is provided for reducing interference in a communication network including a first node and a first node coverage area, a second closed subscriber group (CSG) node, transmitting at a lower power than the first node and located within the first node coverage area, and one or more user equipment (UE) devices located within the first node coverage area. The method includes detecting interference at the second CSG node and determining if the detected interference in uplink is from one or more UE devices that is not connected to the second CSG node. If the detected interference is from one or more UE devices that is not connected to the second CSG node, the method further includes determining if the detected interference is greater than a predetermined interference threshold. If the detected interference is greater than a predetermined interference threshold, the method further includes requesting, by the second CSG node, the interference cancellation (IC) capability of the interfering UE devices, receiving, at the second CSG node, an IC capabilities report from the first node, determining if the interfering UE devices are IC capable based on the received capability report and, if any of the interfering UE devices are not IC capable, the method further includes switching, at the second CSG node, to an IC mode that mutes transmission of reference signals to protect the UEs connected to the first node from interference from the CSG node in the downlink. The method further includes, if any of the

interfering UE devices are not IC capable, initiating a handshake between the first node and the second CSG node to identify a part of bandwidth for muting data transmission and switching, at the second CSG node, to an IC mode that mutes transmission of data causing interference for the first UE device on the identified part of the bandwidth.

In other particular embodiments, a closed subscriber group (CSG) node is provided for reducing interference in a communication network including a first node and a first node coverage area, and one or more user equipment (UE) devices located within the first node coverage area, the CSG node transmitting at a lower power than the first node and located within the first node coverage area. The CSG node includes a processor; a memory coupled to the processor, a transceiver coupled to the processor, and an antenna coupled to the transceiver configured to transmit and receive signals. The processor is configured to detect interference at the CSG node, to determine if the detected interference is from one or more UE devices that is not connected to the CSG node and, if the detected interference in uplink is from one or more UE devices that is not connected to the CSG node, the processor is further configured to determine if the detected interference is greater than a predetermined interference threshold. If the detected interference is greater than a predetermined interference threshold, the processor is further configured to request, by the CSG node, the interference cancellation (IC) capability of the interfering UE devices, receive, at the CSG node, an IC capabilities report from the first node, and to determine if the interfering UE devices are IC capable based on the received capability report. If any of the interfering UE devices are not IC capable, the processor is further configured to switch, at the CSG node, to an IC mode that mutes transmission of reference signals causing the detected interference. Further, if any of the interfering UE devices are not IC capable, the processor is further configured to initiate a handshake between the first node and the second CSG node to identify a part of bandwidth for muting data transmission and to switch, at the second CSG node, to an IC mode that mutes transmission of data causing interference for the first UE device on the identified part of the bandwidth.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated herein and form part of the specification, illustrate various embodiments of the present disclosure and, together with the description, further serve to explain the principles of the disclosure and to enable a person skilled in the pertinent art to make and use the embodiments disclosed herein. In the drawings, like reference numbers indicate identical or functionally similar elements.

FIG. **1**A is an illustration of the multi-layer architecture of a wireless heterogeneous communication network, showing a macro cell with low power CSG cells.

FIG. **1**B is an illustration of major interference scenarios that can be observed in a heterogeneous communication network.

FIG. **2** illustrates exemplary downlink Signal to Interference-plus-Noise Ratio (SINR) of macro UEs for CSG UEs with and without CRS IC capability.

FIG. **3** is a block diagram of a node, as used for example in the system of FIGS. **1**A and **1**B, in accordance with exemplary embodiments.

FIG. **4** is a block diagram of a mobile user equipment (UE) device, as used for example in the system of FIGS. **1**A and **1**B, in accordance with exemplary embodiments.

FIG. **5** is an illustration of the muting of transmission of Cell-specific Reference Signals (CRS) and data both on 50% of the sub-frame length, with the light shaded part showing that data is being transmitted and the dark shaded squares show the CRS signals.

FIGS. **6**A and **6**B are flow charts illustrating the steps in a method for reducing interference in a heterogeneous communication network according to exemplary embodiments, from the perspective of a CSG BS, a macro BS, and a macro UE device.

FIG. **7** is a flow chart illustrating the steps performed by a macro base station in a method for reducing interference in a heterogeneous communication network according to exemplary embodiments.

FIG. **8** is a flow chart illustrating the steps performed by a CSG base station in a method for reducing interference in a heterogeneous communication network according to exemplary embodiments.

FIG. **9** is a flow chart illustrating the steps performed by a CSG base station in a method for reducing interference in a heterogeneous communication network according to an alternate exemplary embodiment.

FIGS. **10**A and **10**B are illustrations of exemplary request and response messaging between a source macro BS and a target CSG BS according to exemplary embodiments.

DETAILED DESCRIPTION

Particular embodiments are directed to methods and devices for reducing interference in heterogeneous communication networks based on inter-cell interference coordination.

Referring now to FIG. **1**A, an architecture of a wireless communication system **100** with a heterogeneous network deployment is illustrated. As shown, wireless communication system **100** includes a wireless network **102**, macro node **106** and low power CSG nodes **108-112**, and mobile devices **120-132**. Examples of node **106** include base stations and relay nodes, such as, for example, high power, and macrocell base stations and relay nodes. Examples of nodes **106-108** include base stations and relay nodes, such as, for example, low power, micro, pico, and femto base stations and relay nodes. Examples of mobile devices **120-132** include wireless User Equipment (UE) and communication devices, such as, for example, mobile telephones, personal digital assistants, electronic readers, portable electronic tablets, personal computers, and laptop computers.

Referring now to FIG. **3**, a block diagram of nodes **106-112**, as used in the system of FIGS. **1**A and **1**B in accordance with exemplary embodiments, is illustrated. As shown in FIG. **3**, nodes **106-112** may include: a data processing system **308**, which may include one or more microprocessors and/or one or more circuits, such as an application specific integrated circuit (ASIC), Field-Programmable Gate Arrays (FPGAs), and the like; network interface **306**; and a data storage system **310**, which may include one or more non-volatile storage devices and/or one or more volatile storage devices (e.g., random access memory (RAM)). The network interface **306** is connected to a transceiver **304**, which is configured to transmit and receive signals via an antenna array **302**. In embodiments where data processing system **308** includes a microprocessor, computer readable program code may be stored in a computer readable medium, such as, but not limited, to magnetic media (e.g., a hard disk), optical media (e.g., a DVD), memory devices (e.g., random access memory), and the like. In some embodiments, computer readable program code is configured such that, when executed by a processor,

the code causes the data processing system **308** to perform steps described below (e.g., steps described below with reference to the flow charts shown in FIGS. **6A-9**). In other embodiments, the nodes **106-112** are configured to perform steps described above without the need for code. That is, for example, the data processing system **308** may consist merely of one or more ASICs. Hence, the features of the present embodiments described above may be implemented in hardware and/or software. For example, in particular embodiments, the functional components of the nodes **106-108** described above may be implemented by the data processing system **308** executing computer instructions, by the data processing system **308** operating independent of any computer instructions, or by any suitable combination of hardware and/or software.

Referring now to FIG. **4**, a block diagram of a mobile device, shown as exemplary device **120** used in the system of FIGS. **1**A and **1**B in accordance with exemplary embodiments, is illustrated. As shown in FIG. **4**, the mobile device **130** may include: a data processing system **406**, which may include one or more microprocessors and/or one or more circuits, such as an application specific integrated circuit (ASIC), Field-Programmable Gate Arrays (FPGAs), and the like; a transceiver **404** for transmitting data to (and receiving data from) nodes **106-108** via an antenna array **402**; and a memory **408**, which may include one or more non-volatile storage devices and/or one or more volatile storage devices (e.g., random access memory (RAM)). In embodiments where data processing system **406** includes a microprocessor, computer readable program code may be stored in a computer readable medium, such as, but not limited, to magnetic media (e.g., a hard disk), optical media (e.g., a DVD), memory devices (e.g., random access memory), and the like. In some embodiments, computer readable program code is configured such that when executed by a processor, the code causes the mobile device **130** to perform steps described below (e.g., steps described below with reference to the flow charts shown in FIGS. **6A-9**). In other embodiments, mobile device **130** is configured to perform steps described above without the need for code. That is, for example, data processing system **406** may consist merely of one or more ASICs. Hence, the features of the present invention described above may be implemented in hardware and/or software. For example, in particular embodiments, the functional components of mobile device **130** described above may be implemented by data processing system **406** executing computer instructions, by data processing system **406** operating independent of any computer instructions, or by any suitable combination of hardware and/or software.

Particular embodiments are implemented consistent with the concept of Carrier Aggregation (CA), which advocates the use of separate bandwidth spectrum among the macro layer **104** and each of the LPN femto layers **114-118** to avoid interference problems between the different cell layers. Certain embodiments limit the interference generated by the CSG cells by de-activating the transmission from the CSG cells on a certain part of the sub-frames from the CSG cells. Referring to FIG. **5**, two subframes are shown, in which the CSG mute their transmissions on part of each subframe. Specifically, in FIG. **5**, the transmission is muted on 50% of the sub-frame, which occurs in every sub-frame. In contrast to the Almost Blank Sub-frames (ABS) technique where the CRS signals are transmitted even in the sub-frame when cells mute their transmissions, the CA technique entails the transmission of CRS signals only on the part of sub-frame **502** where the cells are active, as shown in FIG. **5**. In the transmission of signals from the CSG layer **504**, CRS signals **508** are transmitted only on part of the sub-frame **502** where the cells are active and are not transmitted on the part of the sub-frame **506** where the cell's transmission is muted.

In one embodiment, the UEs **126-130** report their respective Cell-specific Reference Signal Interference Cancellation (CRS-IC) capabilities to the macro cell **104**, which identifies whether the macro UEs which are not able to perform CRS-IC are experiencing high interference from the CSG cells **114-118**. If this lack of CRS-IC capability is determined, the serving macro BS **106** instructs the closest CSG LPN **112** (or a group of CSG LPNs **108-112** in close proximity or even the entire CSG LPN layer) to trigger the CA-based Inter-Cell Interference Coordination (ICIC) technique and accordingly mute the CSG LPN's **112** transmission on a certain part of the sub-frame **506** depending on the Physical Resource Block (PRB) utilization switch to Hybrid Access (HA) mode and thereby provide temporary access to specific UEs **130**. The CSG cell **118** determines if the traffic load in the cell **118** permits it to be silent for the requested amount of time and responds to the macro cell's **106** request by (ACK or NACK messaging). In this way, the amount of interference generated by the transmission of CRS signals is reduced, and the UEs **130** which lack CRS interference cancellation capabilities obtain better service conditions. The interference is reduced not only due to the CRS signals but also the one resulting from the data transmission. The CSG mutes both CRS signals and the data transmission on part of the bandwidth as specified by the ICIC operating ratio. These embodiments improve the overall link quality measurements (LQM) of the UEs **126-130** and reduce the cell edges effect without having impact on the performance of CSG cell **118** itself.

An exemplary embodiment begins with the steps to confirm occurrence of the condition where the macro cell **106** identifies that the UEs **126-130** connected to it are experiencing severe interference from nearby CSG cells **114-118** in the macro cell area **104**. Once this interference is determined, the macro cell **106** triggers the CSG cells **114-118** in the second block to enable the ICIC scheme to protect the nearby macro UEs **126-130**. FIGS. **6**A and **6**B are flow charts illustrating the details of reducing interference in a heterogeneous communication network according to exemplary embodiments, from the perspective of a CSG LPN **108-112**, a macro BS **106**, and a macro UE device **126-130**.

Referring now to FIGS. **6**A, **6**B, and **7**, there are shown flow charts illustrating the steps in methods for reducing interference in a heterogeneous communication network, from the perspective of a macro BS **106**. FIGS. **6**A and **6**B additionally illustrate the sequential message exchange between the macro BS **106**, the CSG BS **112**, and the UEs **130** involved in the procedure.

In a HetNet deployment where CSG LPNs **108-112** are deployed within the macro base station's (BS) **106** coverage area **104** (this information can be available at macro base stations **106** in the area **104** where CSG LPNs **114-118** are deployed), the procedure of receiving link quality measurements from UEs **126-130** in the macro cell **104** is performed at step **702**. This procedure involves reception of Channel Quality Indicator (CQI), Reference Signal Received Power (RSRP), Reference Signal Received Quality (RSRQ), etc. Based on reported measurements by User Equipments (UEs) **126-130**, the link quality measurements of UEs **126-130** in the cell **104** can be estimated at the macro base station **106**. Thereby, the link quality measurements of the links to the UEs **126-130** can be known at the macro base station **106**. Further, the Signal to Interference-plus-Noise Ratio (SINR) for the UEs **126-130** is known at the macro BS **106** based on the received signal strength from the UEs **126-130**. For pur-

poses of simplicity of expression and not limitation, the term, Link Quality Measurement (LQM), will be used hereafter to represent any type of link quality measurements for the UEs **126-130**, including SINR. Exemplary threshold values can be utilized, for example and not limitation, from Table 6.5.1.1 of 3GPP TS 32.762. For example, an acceptable minimum RSRP threshold quality value could be −140 dBm. In addition, exemplary values that can be utilized for X may be greater than −140 dBm and exemplary values that may be utilized for Y may be less than −140 dBm. Other values may also be used dependent on operator preference.

At step **704**, the macro base station checks the quality of the received LQM information to determine if it is below a given LQM threshold level value, LQM_Threshold. In particular, the link quality measurement of the UE **126-130** is compared against a predetermined threshold value to determine if the link quality is below an acceptable level. A low LQM level can be a result of either (1) poor signal strength from the serving BS **104** (the macro BS **104** where this check is done), as a result of (2) high other cell interference from other than the CSG neighbor cells **114-118**, or as a result of (3) high other cell interference originated from the CSG cell **114-118**. To determine if the low signal quality is due to the presence of a neighbor CSG cell **114-118**, at step **706** the RSRP levels from the serving BS **104** and from the strongest interfering neighbor base station **112** are checked at the macro BS **106**. Namely, it is checked whether both (a) the RSRP from the serving base station **104** is good; i.e., it is higher than a given first RSRP threshold, and (b) the RSRP from the strongest neighbor base station, either a neighbor macro base station or an Open Access (OA) femto base station within the macro BS's **106** coverage area **104**, is below a given second RSRP threshold. This interfering neighboring base station can be termed a third node, as compared to the macro first node BS **106** and the CSG second nodes **108-112** generally. Finding both (a) and (b) is an indicator of the presence of a CSG cell **114-118** in close proximity (i.e., neighboring) to the macro UE devices **126-130**. As a form of verification, the serving BS **106**, at step **708**, requests the UE **126-130** to start RSRP reporting of nearby CSG cells **114-118**.

At step **710**, and referring also to FIG. **1**B, the macro BS **106** receives the RSRP reports for neighbor CSG cell **118** from the UE **130**, and at step **712** the macro BS **106** determines if the RSRP of a CSG cell **118** is greater than a certain threshold value, and that the UE **130** is not a member of this CSG **118**. The occurrence of this dual condition confirms that the interference **138** at UE **130** is caused from the CSG neighbor cell **118**.

Determining if the UE **130** is a member of a particular CSG **118** can be accomplished by, for example, two ways:

(1) The macro BS **106** instructs the CSG BS **112** send its "CSG White List", which contains a record of the UEs **132** having access to the CSG cell **118**. The macro BS **106**, upon receipt of this list, can search the list and determine if this specific UE **130** is a member of the target CSG **118** or not.

(2) The macro BS **106** sends a request to the CSG cell **118** to determine if this designated UE **130** is a member of the CSG cell **118** or not. The CSG cell **118** performs a check on its "CSG White List" and responds to the macro BS **106** with an ACK or NACK message.

By the completion of step **712**, it has been determined whether the low LQM level for the macro UE **130** is mainly the result from cell interference **138** originating from a neighbor CSG cell **118**, and the UE **130** cannot avoid this interference because it is not a member of this CSG cell **118**. Once it has been established that the macro UE **130** is suffering from interference from the CSG cell **118**, and the UE **130** is a non-member of the CSG cell **118**, the next procedure is to determine if the Inter-Cell Interference Coordination (ICIC) scheme can or should be triggered at the CSG cell **118** or not. This can be accomplished by using different levels of granularity, for example: (1) enabling ICIC only on the most significant aggressing CSG cell **118** to protect the macro UE **130**; (2) enabling ICIC on a set of CSG cells **112-118** that are in close proximity to the UE **130** experiencing severe interference from CSG cells; or (3) enabling ICIC across the entire CSG LPN cell layer.

The levels of granularity at which the ICIC scheme can be enabled are a function of the traffic in the macro cell area **104** (Physical Resource Block (PRB) utilization) and the distribution of the users **126-130**. For the case when the macro cell **104** is heavily loaded (high PRB utilization), the probability of a UE **126-130** being interfered by the CSG BSs **108-112** is relatively high. Also, in the case where the macro users **126-130** are higher in density in regions with CSG cell clusters, it is expected that the macro UEs **126-130** will experience higher interference.

The macro BS **106** can detect (1) how many UEs **126-130** in its coverage area **104** are affected by transmissions from CSG BSs **108-112** and (2) the number of CSG BSs **108-112** that are interfering with the UEs **126-130** detected in (1). In a first embodiment, the macro BS **106** handles the target BSs **108-112** where the ICIC will be triggered: If the number UEs **126-130** interfered by CSG cells is <X, then the macro BS **106** will enable ICIC at the most significant aggressor **108-112**. If the number of UEs **126-130** interfered by CSG cells is >X<Y, then enable ICIC on a set of CSG cells **108-112** in close proximity to the UE **126-130** experiencing severe interference. If the number of UEs **126-130** interfered by CSG cells is >Y, then enable ICIC across the entire CSG LPN cell layer **114-118**.

In a particular embodiment, CSG BSs **108-112** trigger ICIC mechanisms by themselves based on uplink (UL) interference, as shown by signal **136** in FIG. **1**A. The PRB utilization, or the traffic load, in the macro cell **104** will impact the interference received by the CSG cell **114-118** in the UL. For the case when UEs **126-130** belonging to the macro cell **104** are located close to the CSG cells **114-118** in higher densities, the CSG cells **114-118** will experience high UL interference. This information can be used to independently trigger the ICIC at the CSG cells **114-118**.

If the UL interference experienced at CSG is >X, then enable ICIC in the downlink (DL) to protect the macro UEs **126-130**. The CSG cell **114-118** can use its PRB utilization to determine a suitable ICIC ratio in this case as explained below.

In the embodiments illustrated by FIGS. **6**A-**9**, the first of the above three described levels of granularity is exemplified where the ICIC scheme is triggered only on the most significant CSG aggressor **118**. This procedure can be extrapolated to the above second and third described levels of granularity with only minor adjustments by expanding the triggering of the ICIC scheme for additional CSG cells.

Referring to FIG. **7**, to determine if the ICIC scheme can or should be enabled at the CSG cell **118** causing the severe interference, the macro cell **106** first determines, at step **716**, if the victim UE **130** is capable of cancelling CRS interference (CRS-IC) from neighbor CSG cells **118**. This determination is accomplished by first requesting, by the macro BS **106**, at step **714**, the CRS interference cancellation capabilities of the interfered UEs **130**. The procedure of identifying the CRS-IC capabilities of a UE **130** is also discussed below with reference to FIG. **8**. If the UE **130** is determined to be

CRS-IC capable at step **716**, the macro BS **106** need not take any further action because it is anticipated that the macro UE **130** will not be considerably affected by the interference **138** created by the CRS from the neighbor CSG cell **118** because of the UE's **130** interference cancellation capabilities, and the process reverts back to step **702** to determine, or await, receipt of link quality measurements from the macro UEs **126-130**.

However, in case the UE **130** cannot cancel interference originating from CRSs from the neighbor CSG cell **118**, then, at step **718**, the macro BS **106** starts the procedure to trigger an ICIC scheme at the CSG cell **118** to protect the victim UE **130**. To initiate the ICIC mechanism, the macro cell **104** needs to know the Physical Resource Block (PRB) utilization of the aggressing CSG cell **118** to determine the appropriate ICIC operating ratio (X:Y). The need for this information arises from 3GPP specifying different ratios for the operation of Carrier Aggregation (CA)-based ICIC mechanisms, including 1:4 and 1:8 ratios, for example and not limitation, where the CSG cells **114-118** mute their transmissions on 25% and 12.5% of the bandwidth, respectively. However, based on performed simulations, the PRB utilization of the CSG BSs **108-112** often does not exceed 10%, even for a heavily loaded traffic scenario. Thus, more aggressive muting ratios can be employed at the CSGs **114-118** based on the operators' strategy.

The ICIC operating ratio can be a function of the PRB utilization of the CSG cells alone, or both the macro cell **104** and the CSG cells **114-118**. The ratio can also be modified by the operators, depending, for example, on whether they would prefer an aggressive approach to the ICIC ratio or a more subtle one. There can be several ways to calculate the ratio, such as, for example:

(1) Based on CSG Cell PRB Utilization Only:

If the PRB utilization of CSG cell<A %, then use an ICIC Ratio (X1:Y1);

if the PRB utilization of CSG cell>A %<B %, then use an ICIC Ratio (X2:Y2);

if the PRB utilization of CSG cell>B %<C %, the use an ICIC Ratio (X3:Y3);

if the PRB utilization of CSG cell>C %, then use an ICIC Ratio (X4:Y4), where A<B<C. The Ratio (X1:Y1) comprises X1: number of inactive frames and Y1: total number of frames in the CSG cell **114-118**, where

$$\text{Ratio}(X1:Y1)>\text{Ratio}(X2:Y2)>\text{Ratio}(X3:Y3)>\text{Ratio}(X4:Y4).$$

(2) Based on the PRB utilization information of both the CSG **114-118** and the macro cells **104**, an additional optimization of option **1** described above can be performed. In this case, the macro PRB utilization is also considered for calculating the ICIC Ratio, as follows:

If the macro PRB utilization<A1% and the CSG PRB utilization<B1%, then use an ICIC Ratio (X1:Y1);

If the macro PRB utilization>A1%<A2% and the CSG PRB utilization<B1%, then use an ICIC Ratio (X2:Y2);

If the macro PRB utilization>A2%<A3% and the CSG PRB utilization<B1%, then use an ICIC Ratio (X3:Y3);

If the macro PRB utilization>A3% and the CSG PRB utilization<B1%, then us an ICIC Ratio (X4:Y4). The Ratio (X1:Y1) comprises X1: number of inactive frames and Y1: total number of frames in the CSG cell **114-118**, where

$$\text{Ratio}(X1:Y1)>\text{Ratio}(X2:Y2)>\text{Ratio}(X3:Y3)>\text{Ratio}(X4:Y4).$$

Thus, at step **718**, the macro BS **106** requests the aggressing CSG cell **118** for its PRB utilization and determines at step **720**, based on the received PRB utilization, the ICIC operating ratio (X:Y) to be used. Having established the operating ratio (X:Y), the macro BS **106** then instructs the CSG cell **118** at step **722** to operate in ICIC mode with the specified ratio to protect the victim macro UE **130**. Under the instructed ICIC mode, Carrier Aggregation (CA) is applied to the CSG cell **118** in question. Namely, the carrier aggregation policy determines that a ratio (X:Y) of the entire CSG transmission bandwidth is going to be used in the external zone of the CSG cell **118**. In certain cases, this rule can be applied to the whole CSG cell **118**.

The time period for the CSG **118** to be operating in ICIC mode is also dependent on the operator strategy and on the amount of traffic in the macro cell **104** and CSG cell **118**. If the traffic load in the CSG cell **118** is not high, the ICIC scheme can be enabled for a relatively longer duration to protect the macro UEs **130** from the transmission of CRS signals. For example, and not limitation, exemplary duty cycles that can be utilized include, but are not limited to: 1/8, 2/8, 3/8, 4/8, and 3/20. This new ICIC policy is applied up to the moment of the next message arriving from the macro BS **106**. This ICIC mode time period during which a specific policy is active depends on such factors as the load in the CSG **118**, the activity of the UE **130** receiving this high interference, among others.

It is noted here that the above discussion has described embodiments primarily from the perspective of the macro BS **106**. The following discussion describes embodiments from the perspective of the CSG BS **112**, where the macro BS **106** has proposed an operational bandwidth with the operating ratio (X:Y); and the CSG BS **112** can either accept or reject the proposal of the macro BS **106**.

Referring now to FIGS. **6**A, **6**B, and **8**, flow charts are provided illustrating the steps performed by a CSG base station **112** in methods for reducing interference in a heterogeneous communication network. At step **802**, the CSG base station **112** receives a request from the macro BS **106** to report its Physical Resource Block (PRB) utilization so that the macro BS **106** can determine an appropriate ICIC (bandwidth) operating ratio (X:Y) based on the traffic in the CSG cell **118**. The request contains the UE's **130** Cell Radio Network Temporary Identifier (C-RNTI), Temporary Mobile Subscriber Identity (TMSI), or any other form of the UE's **130** identity and, optionally, the reason for requesting the PRB utilization information. Upon receipt of this request, the CSG BS **112** optionally performs a security check at step **804** to determine if the PRB request from the macro BS **104** has included a reason for the requesting the information. If no reason has been provided, the CSG BS **112** can reject the request in one of several ways, including transmitting NACK to the macro BS **106** at step **820**. Otherwise, the CSG BS **112** asks the macro BS **106** (at step **806**) to transmit information about the CRS interference cancellation capabilities of the UE **130**, to obtain the CRS-IC capability of the UE **130** and/or to alternately verify the legitimacy of the PRB utilization request.

At step **808**, the CSG BS **112** receives the response from the macro BS **106**, with the information on the specific UE's **130** CRS IC capability. At step **810**, the CSG BS **112** checks if the UE **130** is able to cancel CRS interference from neighboring cells **118**. If the UE **130** is CRS-IC capable, the CSG cell **118** transmits NACK to the macro BS **106** at step **812** to inform the macro cell **106** that the interfered UE **118** is capable of canceling the CRS interference.

Steps **804**, **806**, and **808** can be considered optional, but can be performed as an additional security measure performed at the CSG BS **112** for verifying the legitimacy of the macro BS **106** information request made at step **802** and for subse-

quently permitting temporary access to the CSG BS **112** by the macro BS **106**. However, the message transmitted by the serving BS **106** to the CSG BS **112** requesting PRB utilization information might already contain the reason for asking the temporary access by the macro BS **106** to this CSG cell. Further, the UE **130** might be indicated as not being capable of CRS-IC, in which case these steps are necessary to subsequently initiate the appropriate CRS interference cancellation at the UE **130**.

If the designated UE **130** is determined to not be CRS-IC capable, the CSG BS **112** then discloses its PRB utilization to the macro BS **106** at step **814** for the macro BS **106** to determine an appropriate ICIC operating ratio (X:Y) at step **720**. The ICIC (bandwidth) operating ratio (X:Y) is then communicated to the CSG BS **112** at step **816**. The macro BS **106** can additionally include its own PRB utilization as part of the message to the CSG BS **112** containing the ICIC operating ratio (X:Y). This additional PRB utilization information can be used by the CSG BS **112** to determine the amount of time it should keep the ICIC scheme enabled, as discussed above. For high macro PRB utilization, muting part of the CSG bandwidth for longer periods can be beneficial by limiting the interference generated from the transmission of CRS signals for a longer period of time.

At step **818**, the CSG BS **112** determines if the proposed operating frequency ratio (X:Y) is acceptable based on the PRB utilization of the CSG cell **118**. If the ICIC (frequency) operating ratio (X:Y) is found to be acceptable, then the CSG BS **112** sends an ACK message to the macro BS **106** at step **822**, and the CSG BS **112** switches to an ICIC mode at step **824** and mutes its CRS transmission on the part of the bandwidth specified by the ratio. However, if the ratio is deemed as unacceptable due to high CSG **118** traffic load, then a NACK message is sent to the macro BS **106** at step **820** with a proposed new ICIC operating ratio (X:Y) from the CSG BS **112**, and the handshaking of steps **720** and **816-820** between the macro BS **108** and CSG cell **118** is repeated until agreement on the ICIC operating ratio (X:Y) is reached. Once the ICIC operating ratio is determined to be acceptable, the CSG BS **112** sends an ACK message to the macro BS **106** at step **822** and switches to the ICIC mode, as discussed above.

In a particular embodiment, where the UE **130** affected by interference from the CSG BS **112** is determined at step **716** to be capable of cancelling interference from the neighbor cells CRS transmissions, then the aggressor CSG BS **112** can be instructed to apply an evolved ICIC mode based on Almost Blank Sub-frames (ABS) or based on low power subframes. This solution is effective if the load in the CSG cell **118** is such that the use of ABS or the like technique instead of using ICIC based on carrier aggregation (CA) (frequency bandwidth division) is effective.

The CSG cells **114-118** are generally customer owned and customer deployed, often for home usage. Therefore, the customers pay an additional premium to buy the WiFi-like eNBs to be set up residentially to avoid coverage and capacity problems. In such cases, the requirement to mute CSG CRS transmissions for a certain period could be objectionable. In such cases, instead of completely muting the transmission of CRSs, the low power sub-frame technique can be used. This method entails the CSG BSs **108-112** transmitting at relatively lower powers for a certain time period to protect the macro UEs **126-130**. The lower power transmissions limits the interference experienced by the macro UEs **126-130** and avoids the muting of CSG CRS transmissions at the same time. In general, the CSG cell **114-118** radius spans from 10 m to 15 m and, thus, this solution can be applied since the UEs **120-124** and **132** are located close to their serving CSG BSs **108-112** and, hence, the DL transmission power lever from these BSs **108-112** is still sufficient (even after DL power reduction) for acceptable communication. However, for the uncommon circumstances of larger radius CSG cells **114-118**, limiting the transmission power from the CSG BSs **108-112** can lead to poor radio strength for the connected UEs.

Referring again to FIG. **1**A and also to FIG. **9**, another embodiment for triggering the ICIC mechanism to reduce interference at macro UEs **126-130** is the detection, at the CSG BS **112** (at step **902**), of high uplink (UL) interference **136** from nearby UEs **128** that are not connected to that CSG BS **112**. If the CSG BS **112** experiences high UL interference, it may mean there are macro UEs **128** located in close proximity and, therefore, the CSG BS **112** can likely also cause interference problems for these UEs **128** in the downlink (DL) **138** from the CSG BS **112**. Upon detecting UL interference, the CSG BS **112**, at step **904**, checks to determine whether the UL interference is greater than a predetermined UL interference threshold value. If the level of interference is not greater than the threshold value, the process returns to step **902** to monitor possible UL interference at the CSG BS **112**. Otherwise, at step **906**, the CSG BS **112** requests, from the macro BS **106**, the CRS IC capabilities of the interfering UEs **128**. Upon receipt of the CRS IC capabilities report or information, the CSG BS **112**, at step **908**, checks whether any of the interfering UEs **128** are CRS-IC capable. If the UEs **128** are CRS-IC capable, the CSG BS **112** does nothing more, and interference checking can proceed at step **902**. If any UEs **128** are not CRS-IC capable, then the process can alternately trigger one of at least two exemplary procedures.

In one particular embodiment, the CSG BS **112** can request PRB utilization from the macro BS **106** at step **914** to determine how long the CSG BS **112** should mute its CRS transmissions. A higher PRB utilization of the macro BS **106** indicates a higher traffic load in the macro cell **104**; and, thus, a higher probability of macro users **126-130** being interfered by the CRS transmissions of the CSG BSs **108-112**. Upon receipt of the PRB utilization information at step **916**, the CSG BS **112** can determine, at step **918**, the ICIC operating ratio (X:Y). At step **920**, the CSG BS **112** switches to ICIC mode, and stops the transmission of both data and CRS signals on the specified part of bandwidth based on the determined ICIC operating ratio. Upon end of the ICIC mode period, the process returns to step **902** to monitor for, or detect, UL interference.

In another particular embodiment, the PRB utilization is not needed from the macro BS **106**. Instead, the CSG BS **112** can monitor the UL interference **136** and can mute its transmissions as long as the uplink interference **136** exceeds the predetermined interference threshold level. Alternately, the CSG BS **112** can stop muting its transmissions after a predetermined or calculated number of sub-frames have been transmitted by the CSG BS **112**, even if the UL interference **136** still exceeds the threshold. The maximum number of sub-frames can be pre-determined by the operator, or it can be calculated at step **910** based on the PRB utilization of the CSG cell **118**: If the PRB utilization of the CSG cell **118** is <X %, then the maximum number of sub-frames to be transmitted in CRS muted form is A; and if the PRB utilization of the CSG cell **118** is >X %, then the maximum number of sub-frames to be transmitted in CRS muted form is B, where A>B. At step **912**, the CSG BS **112** switches to ICIC mode, for the calculated number of sub-frames.

Several of the above descriptions involve embodiments in which the decisions and steps are based on a single UE **130** receiving high interference from the CRS transmissions from a neighbor CSG BS **112**. These embodiments can be equally

applied for the case where the interference is being experienced by a number, N, of macro UEs **126-130+**. For example, the determination to switch to ICIC mode at steps **722** and **824** can be additionally based on frequency division or time division, based on whether the highest number, or an M number, of the UEs receiving high interference can cancel the interference or not.

The embodiments discussed here can optimally be applied to UEs **126-130** moving at low or medium speed. An additional advantage of these embodiments is that they are compatible with at least 3GPP LTE Rel. 8.

In terms of performance, implementation of these embodiments produce gains in DL transmissions in all performance measurements, such as cell edge UE SINR and the cell edge UE throughput. Moreover, enabling the ICIC scheme at the CSG cells **114-118** does not necessarily impact the CSG cell's performance, as the PRB utilization of the LPN cells is found to be less than 10% even for heavily loaded traffic scenarios, as discussed above.

Additional embodiments utilize the exchange of messages for performing handshakes between the macro BS **106** and the CSG BS **112** as part of the methods for reducing interference as explained above and as shown in FIGS. **6A-9**. The messages below are described for the scenario where X2AP interface is connecting the serving macro BS **106** with the target CSG BS **112**. Therefore, the terminology below is taken from the 3GPP TS 36.423 X2 Application Protocol specification (X2AP). For the circumstances where the X2 interface is not available, the communication between the serving macro BS **106** and the target CSG BS **112** can be accomplished via the S1AP interface. While the terminology for X2AP and its messages is somewhat different from the S1AP terminology, the content of the X2AP messages and its protocol mechanisms are similar as in S1AP.

As part of the above-described exemplary embodiments, the macro BS **106** and the CSG BS **112** perform a handshake at steps **718**, **720**, **722**, **802**, and **814** to exchange the PRB utilization information of the target BS **112**. One of the procedures to perform this handshake is exemplified in FIG. **10**A, where a separate X2AP message (i.e. a PRB utilization report request) is sent from the macro BS **106** to the target CSG BS **112** to inquire about the PRB utilization of the CSG cell **118**. In this message, the source macro BS **106** instructs the CSG BS **112** to report its PRB utilization and also includes the reason for this request (i.e., for example, because the UE **130** is CRS-IC incapable and ICIC must be enabled). This information is used by the macro BS **106** to determine the proper ICIC operating ratio (X:Y) that is to be applied at the CSG cell **118**.

The CSG BS **112** performs the (optional) security checks in steps **804**, **806**, and **808** of FIGS. **6**A, **6**B, and **8**; and in the case of legitimate requests, the CSG BS **112** responds with a "PRB utilization report response" message to the macro BS **106** at step **812**. However, in case of an unauthorized PRB utilization report request, a Negative-Acknowledgement can be sent back to the macro BS **106** by the CSG BS **112** with an included rejection reason for refusing the requested disclosure of information (e.g., for example, because: the UE **130** is CRS IC Capable).

The above exemplary embodiments also involve a handshake between the macro BS **106** and the CSG BSs **108-112** to establish the amount of bandwidth over which the CSG BSs **108-112** should mute their transmission, called the ICIC handshake, exemplified in FIG. **10**B. Once the macro BS **106** acquires the information about the PRB utilization of the CSG cell at step **814**, it decides the muting bandwidth of the CSGs (ICIC muting ratio) at step **720**, and sends a request to the CSG BS **112** at step **722** to enable ICIC mode at the CSG BS **112** using the specified operating muting ratio. The target CSG BS **112** then inspects its PRB utilization and verifies whether it can enable the ICIC using the muting ratio specified by the source macro BS **106**. If the ICIC muting ratio specified by the source macro BS **106** is deemed feasible, then the CSG BS **112** enables the ICIC mode and responds with an ACK in the ICIC response message at step **822**. However, if the specified muting ratio is considered unfeasible by the target CSG BS **112** due to higher PRB utilization, then a NACK is sent as a response to the enable ICIC mode request at step **820**, with a new proposed muting ratio; and the handshake is repeated.

Optionally, the macro BS **106** can include its own PRB utilization as part of the enable ICIC mode request at step **722** so as to aid the CSG BS **112** in determining the time for which the CSG BS **112** should mute its transmissions on part of the bandwidth specified by the operating muting ratio.

While various embodiments have been described above, it should be understood that they have been presented by way of example only, and not limitation. Thus, the breadth and scope of the present disclosure should not limited by any of the above-described exemplary embodiments. Moreover, any combination of the above-described elements in all possible variations thereof is encompassed by the disclosure unless otherwise indicated herein or otherwise clearly contradicted by context.

Additionally, while the processes described above and illustrated in the drawings are shown as a sequence of steps, this was done solely for the sake of illustration. Accordingly, it is contemplated that some steps may be added, some steps may be omitted, the order of the steps may be re-arranged, and some steps may be performed in parallel.

What is claimed is:

1. A method for reducing interference in a communication network including a first node and a first node coverage area, a second closed subscriber group (CSG) node, transmitting on a bandwidth at a lower power than the first node and located within the first node coverage area, and one or more user equipment (UE) devices located within the first node coverage area, the method comprising:

receiving link quality measurement (LQM) information from the one or more UE devices;

determining, based on the received link quality measurement information, if a link quality value for a first UE device of the one or more UE devices is below a predetermined link quality threshold value and, if the link quality value is below the predetermined link quality threshold value, the method further comprising:

(i) determining, based on the received link quality measurement information, if the link quality value is caused by the second CSG node and, in response to determining that the link quality value is caused by the second CSG node, the method further comprising:

(ii) determining if the first UE device is a member of the second CSG node and, in response to determining that the first UE device is not a member, the method further comprising:

(iii) determining if the first UE device includes an interference cancellation (IC) capability and, in response to determining that the first UE device does not include an IC capability, the method further comprising:

(iv) instructing the second CSG node to operate in an IC mode that mutes transmission of the second CSG node on a part of the bandwidth causing interference for the first UE device.

2. The method according to claim 1, wherein the communication network comprises a heterogeneous network.

3. The method according to claim 1, wherein the second CSG node comprises a micro, pico, or femto node.

4. The method according to claim 1, wherein the link quality measurement information comprises one or more of Channel Quality Indicator (CQI), Reference Signal Received Power (RSRP), and Reference Signal Received Quality (RSRQ).

5. The method according to claim 1, wherein determining if the link quality value for the first UE device is below a predetermined link quality level comprises comparing the LQM for the first UE device with a LQM threshold value to determine if the LQM for the first UE device is less than the LQM threshold value.

6. The method according to claim 1, wherein determining if the link quality value is caused by the second CSG node comprises comparing a first reference signal received power, RSRP, for the first node with a first RSRP threshold value to determine if the first RSRP is greater than the first RSRP threshold value and comparing a second RSRP for a third node located within the first node coverage area with the strongest RSRP value with a second RSRP threshold value to determine if the second RSRP is less than the second RSRP threshold value.

7. The method according to claim 1, further comprising:

instructing the second CSG node to send a list of UE devices that are members of the second CSG node;

receiving, at the first node, the list of member UE devices; and

searching the received list of member UE devices list to determine if the first UE device is a member of the second CSG node.

8. The method according to claim 1, further comprising querying the second CSG node to determine if the first UE device is a member of the second CSG node.

9. The method according to claim 1, wherein the IC capability comprises inter-cell interference coordination.

10. The method according to claim 1, wherein the link quality value for the first UE device being below the predetermined link quality threshold value is caused by the transmission of data signals from the second CSG node.

11. The method according to claim 1, wherein the link quality value for the first UE device being below the predetermined link quality threshold value is caused by the transmission of cell-specific reference signals from the second CSG node.

12. The method according to claim 1, further comprising, after determining if the first UE device includes an interference cancellation (IC) capability and prior to instructing the second CSG node to operate in an IC mode:

requesting Physical Resource Block (PRB) utilization information for the second CSG node;

receiving the PRB utilization information for the second CSG node; and

determining, based on the received PRB utilization information, an inter-cell interference coordination, ICIC, operating ratio, wherein instructing the second CSG node causes the second CSG node to operate in an IC mode based on the ICIC operating ratio.

13. A first node operable to reduce interference in a communication network including a first node coverage area, a second closed subscriber group (CSG) node, transmitting on a bandwidth at a lower power than the first node and located within the first node coverage area, and one or more user equipment (UE) devices located within the first node coverage area, the first node comprising:

a processor;

a memory coupled to the processor;

a transceiver coupled to the processor; and

an antenna coupled to the transceiver configured to transmit and receive signals;

wherein the processor is configured to:

receive link quality measurement (LQM) information from the one or more UE devices;

determine, based on the received link quality measurement information, that a link quality value for a first UE device of the one or more UE devices is below a predetermined link quality threshold value and, in response to determining that the link quality value is below the predetermined link quality threshold value, the processor further configured to:

(i) determine, based on the received link quality measurement information, if the link quality value is caused by the second CSG node and, in response to determining that the link quality value is caused by the second CSG node, the processor further configured to:

(ii) determine if the first UE device is a member of the second CSG node and, in response to determining that the first UE device is not a member, the processor further configured to:

(iii) determine if the first UE device includes an interference cancellation (IC) capability and, in response to determining that the first UE device does not include an IC capability, the processor further configured to:

(iv) instruct the second CSG node to operate in an IC mode that mutes transmission of the second CSG node on a part of the bandwidth causing interference for the first UE device.

14. The first node according to claim 13, wherein the communication network comprises a heterogeneous network.

15. The first node according to claim 13, wherein the second CSG node comprises a micro, pico, or femto node.

16. The first node according to claim 13, wherein the link quality measurement information comprises one or more of Channel Quality Indicator (CQI), Reference Signal Received Power (RSRP), and Reference Signal Received Quality (RSRQ).

17. The first node according to claim 13, wherein the processor, configured to determine if the link quality value for the first UE device is below a predetermined link quality threshold value, is also configured to compare the LQM for the first UE device with a LQM threshold value to determine if the LQM for the first UE device is less than the LQM threshold value.

18. The first node according to claim 13, wherein the processor, configured to determine if the link quality value is caused by the second CSG node, is also configured to:

compare a first reference signal received power, RSRP, for the first node with a first RSRP threshold value to determine if the first RSRP is greater than the first RSRP threshold level; and

compare a second RSRP for a third node located within the first node coverage area with the strongest RSRP value with a second RSRP threshold value to determine if the second RSRP is less than the second RSRP threshold value.

19. The first node according to claim 13, wherein the processor is further configured to:

instruct the second CSG node to send a list of UE devices that are members of the second CSG node;

receive, at the first node, the list of member UE devices; and

search the received list of member UE devices to determine if the first UE device is a member of the second CSG node.

20. The first node according to claim **13**, wherein the processor is further configured to query the second CSG node to determine if the first UE device is a member of the second CSG node.

21. The first node according to claim **13**, wherein the IC capability comprises inter-cell interference coordination.

22. The first node according to claim **13**, wherein the link quality value for the first UE device being below the predetermined link quality threshold value is caused by the transmission of data signals from the second CSG node.

23. The first node according to claim **13**, wherein the link quality value for the first UE device being below the predetermined link quality threshold value is caused by the transmission of cell-specific reference signals from the second CSG node.

24. The first node according to claim **13**, wherein the processor is further configured to, after determining if the first UE device includes an interference cancellation (IC) capability and prior to instructing the second CSG node to operate in an IC mode:

request Physical Resource Block (PRB) utilization information for the second CSG node;

receive the Physical Resource Block (PRB) utilization information for the second CSG node; and

determine, based on the received PRB utilization information, an inter-cell interference coordination, ICIC, operating ratio, wherein the instructing the second CSG node causes the second CSG node to operate in an IC mode based on the ICIC operating ratio.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO.	: 9,066,357 B2
APPLICATION NO.	: 13/731804
DATED	: June 23, 2015
INVENTOR(S)	: Dimou et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

IN THE SPECIFICATION

In Column 14, Line 62, delete "UE 118" and insert -- UE 130 --, therefor.

In Column 17, Line 2, delete "UEs 126-130+." and insert -- UEs 126-130. --, therefor.

Signed and Sealed this
Sixteenth Day of February, 2016

Michelle K. Lee

Michelle K. Lee
Director of the United States Patent and Trademark Office