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(71) Applicant: **HUAWEI TECHNOLOGIES CO., LTD.** [CN/CN]; Huawei Administration Building, Bantian,Longgang District, Shenzhen, Guangdong 518129 (CN).

(72) Inventors: **DE DOMENICO, Antonio**; Huawei Technologies Duesseldorf GmbH, Riesstr. 25, 80992 Munich (DE). **PIOVESAN, Nicola**; Huawei Technologies Duesseldorf GmbH, Riesstr. 25, 80992 Munich (DE). **LOPEZ-PEREZ, David**; Huawei Technologies Duesseldorf GmbH, Riesstr. 25, 80992 Munich (DE). **ZHAO, Nan**; Huawei Administration Building, Bantian,Longgang District, Shenzhen, Guangdong 518129 (CN). **BAO, Hongqiang**; Huawei Technologies Duesseldorf GmbH, Riesstr. 25, 80992 Munich (DE).

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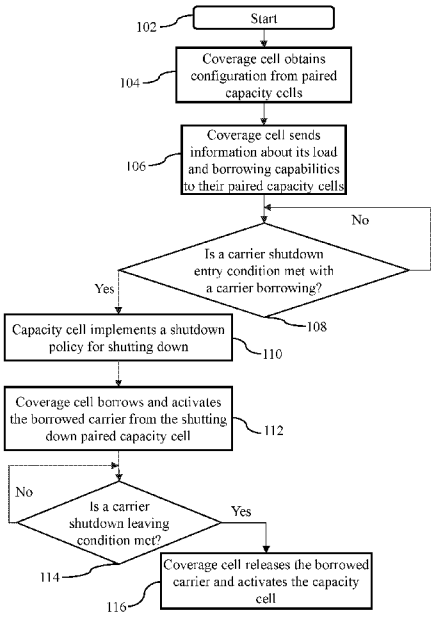

FIG. 1

(57) Abstract: Controlling carrier shutdowns in a multi-carrier cellular network includes obtaining, by a coverage cell in the multi-carrier cellular network, an information about Active Antenna Unit, AAU, configuration of one or more capacity cells paired with the coverage cell. The coverage cell sends an information about coverage cell load and carrier borrowing capabilities of an AAU of the coverage cell to the paired capacity cells. Each of the paired capacity cells determines if a carrier shutdown entry condition of the capacity cell is met with a carrier borrowing by the coverage cell in accordance with the carrier borrowing capabilities. A capacity cell which carrier shutdown entry condition is determined to be met with the carrier borrowing shuts down, while its carrier is borrowed by the coverage cell using the AAU configuration of the capacity cell to activate the borrowed carrier, if it is determined by the coverage cell that a carrier borrowing condition is met.

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METHOD OF CONTROLLING CARRIER SHUTDOWNS IN A MULTI-CARRIER CELLULAR NETWORK

TECHNICAL FIELD

The disclosure relates generally to controlling carrier shutdowns in a multi-carrier cellular network, and more particularly, the disclosure relates to a method of controlling carrier shutdowns in the multi-carrier cellular network.

BACKGROUND

Third-generation partnership project new radio, 3GPP NR, deployments typically provide an improved energy efficiency of around four times (4x) with respect to the third generation partnership project, 3GPP, long term evolution, LTE, due to their larger capacity and improved hardware. However, the 3GPP NR sites are estimated to consume up to three times (3x) more energy than the LTE ones, due to the more processing required to handle wider bandwidth and more antennas. This may increase carbon emissions and electricity bills of operators.

To address this problem and further enhance the energy efficiency of cellular networks, LTE and new radio base stations, BSs, implement energy saving schemes, which allow a BS to dynamically switch OFF part of its hardware to reduce its power consumption.

In order to be energy efficient, an existing solution uses a carrier shutdown function that enables carriers to be shutdown within operator-specified periods.

In the context of carrier shutdown, coverage and capacity cells are introduced in the 3GPP to allow energy saving through an inter-cell coordination. The capacity cells are high-band cells and can be shutdown. The coverage cells are manually identified low-band cells that provide basic coverage, and cannot be shutdown. Each capacity cell is associated, through inter-frequency co-coverage relationships, with a subset of coverage cells. When the sum load of the capacity and coverage cell pair is not high, the traffic of the capacity cell may be migrated towards its coverage cell and the capacity cell may be shutdown. When the coverage cell load increases, it may activate the shutdown capacity cell.

Further, the capacity cell can only be shutdown, if the coverage cell is identified and paired with it. Otherwise, the coverage and capacity requirements may not be guaranteed to the users served by the switched OFF capacity. Further, based on momentary conditions of the coverage and capacity cells (e.g. their sum load), the capacity cell may or may not (1) initiate an inter-frequency handover, and (2) a shutdown. Similarly, when the load increases at the coverage cells, this may activate the dormant capacity cell. Therefore, in the current cellular network, there is a need to keep the coverage cell load as low as possible to increase the opportunity to switch OFF capacity cell and augment their shutting down time.

With the advent of the fifth-generation, 5G, era, a number of frequency bands added to a base station is increasing. Over 70% of operators have more than 5 frequency bands, and more frequency bands (e.g. millimeter wave bands) may be added to future cellular networks. The mainstream 2G/3G/4G base stations are in the form of combination of base band unit, BBU, radio remote unit, RRU, and antenna. In the 5G era, they are evolving into the form of BBUs and active antenna unit, AAU. More specifically, a radio unit, which is in charge of performing transmit, TX,/ receive, RX, signal processing for a cell may be the form of: (1) an RRU, which exchanges digital signals with the base band unit through a fiber optic cable, and analog signals with passive antenna elements through a coaxial cable, or (2) an AAU, which integrates the RRU functionality and the passive antenna elements into one unit, and provides a hardware and logic to (i) control the precoding coefficients of each passive antenna element and (ii) combine/divide the digital signals from/to each passive antenna element. Existing RRUs/AAUs are multi-carrier, and use a wideband power amplifier, PA, to operate such multiple carriers jointly.

When compared to single-band PAs, the wideband PA provides an increased energy efficiency. This is mainly due to: (i) by integrating multiple carriers together, the total transmit power managed by the wideband PA is greater, thus allowing wideband PAs to operate in higher efficiency areas, and (ii) the static power consumption of the wideband PA increases sub-linearly with respect to a number of carriers, as part of signal processing components that can be shared among the different carriers. Further, the use of wideband PAs has an impact on network energy saving methods. The

wideband PA can only be switched OFF, if all of its supported carriers are shutdown. Otherwise, if one of them is active, the wideband PA remains active, thus limiting the energy savings at the cellular network side. Therefore, the paired coverage and capacity cells have to be deployed on distinct AAUs to maximize energy saving through carrier shutdown.

Further, the 3GPP is introduced with a concept of co-coverage relationships where the capacity and basic cells are automatically identified using a vendor-specific procedure. For example, in the capacity cells, the base station randomly selects user equipment's, UEs, and delivers measurement control messages to measure all inter-frequency cells. This may leverage the 3GPP self-organizing network, SON, automatic neighboring relation, ANR, framework. The base station then receives the corresponding UE measurement reports, MRs, and estimates a coverage overlap by dividing a number of times that the coverage cell is the strongest cell with a number of times that measurement control messages are delivered for the frequency of the neighboring basic cell.

Typically, the paired coverage and capacity cells are deployed on distinct AAUs to maximize energy saving through carrier shutdown, i.e.,, the paired coverage and capacity cells do not share the same power amplifier. When the carrier shutdown feature is activated, the carrier shutdown entry conditions decide whether a capacity cell goes into carrier shutdown at a given point in time. The approach is based on the following principles: (1) the capacity cells may decide to enter dormant mode autonomously or based on information exchanged with the coverage cell, (2) switch OFF decisions/requests may be based on information locally available in the access network node, including load information of both the coverage and capacity cells, (3) switch ON may be performed based upon requests from one or more neighbour inter-radio access technology, RAT, nodes, or based on internal node policies (e.g. periodic switch ON, maximum switch OFF time, etc.), (4) Intra-radio access technology and Inter-RAT neighbour nodes may be informed after ON/OFF decision is made, (5) to perform energy saving more efficiently, some energy saving parameters may be exchanged between inter-RAT neighbour cells if required (e.g. traffic thresholds, time duration, power consumption and so on).

Further, when some capacity cells are not active and the load increases on the access cellular network, the coverage cells may not know the appropriate capacity cells to wake-up. The overloaded coverage cells may request wake-up of one or more of the neighbouring dormant capacity cells based on the co-coverage relationships. However, a final decision to leave dormant mode is taken by the capacity cell based on information locally available.

Although the above techniques may reduce the energy consumption of cellular networks, their current implementation may lead to limited user performance due to the handover mechanisms and the limited capacity of coverage layer. Further, continuous deactivation and activation of the capacity cells may result in limited energy efficiency gains. The network spectrum efficiency is reduced due to the momentary deactivation of the capacity cells and unused spectrum of these capacity cells.

Another existing solution employs a cell switching and spectrum leasing framework to maximize the revenue of the primary network, PN, by leasing its owned spectrum to a secondary network, SN. This framework analyses the energy saving and spectrum leasing revenue with the quality of service, QoS, tradeoff, and designs an optimal cell switching and spectrum leasing policy that leads to a maximum revenue for the PN, while ensuring that the QoS of the PN is maintained. However, this framework does not focus on the coverage and load issues due to carrier shutdown.

Another existing solution provides a cell switching and spectrum leasing framework that learns using an algorithm and maximizes the revenue of the primary network, PN, while ensuring that the QoS of the PN is maintained. In this solution, the PN may lease its owned spectrum to a secondary network, SN. Further, the cell switching and spectrum leasing problem is formulated as a binary integer programming problem, which is solved by a heuristic based on simulated annealing. However, this solution does not focus on coverage and load issues due to carrier shutdown.

Yet another existing solution discloses a method for enabling frequency resource negotiation in a defined set of nearby access points. This solution realizes channel borrowing in a WLAN, and maintains or improves network throughput. However, it does not focus on energy saving and coverage and load issues due to carrier shutdown.

Another existing solution discloses a channel borrowing method that reduces congestion in cellular networks, where based on user requests that cannot be fulfilled, a first cell requests for a momentary number of channels to a nearby cell, which allows the first cell to use those channels based on its expected traffic. However, it does not focus on channel borrowing to extend the shutting down time of capacity cells.

Another existing solution discloses a network scheduling method for coordinating energy-saving management of a base station. This method enables base stations to implement shutdown modes including channel and carrier shutdown modes in a coordinated way. However, it does not focus on channel borrowing to extend the shutting down time of capacity cells.

Therefore, there arises a need to address the aforementioned technical problem/drawbacks in controlling a carrier shutdown in the multi-carrier cellular network.

SUMMARY

It is an object of the disclosure to provide a method of controlling carrier shutdowns in a multi-carrier cellular network while avoiding one or more disadvantages of prior art approaches.

This object is achieved by the features of the independent claims. Further, implementation forms are apparent from the dependent claims, the description, and the figures.

The disclosure provides a method of controlling carrier shutdowns in a multi-carrier cellular network.

According to a first aspect, there is provided a method of controlling carrier shutdowns in a multi-carrier cellular network. The method includes obtaining, by a coverage cell in the multi-carrier cellular network, an information about Active Antenna Unit, AAU, configuration of one or more capacity cells paired with the coverage cell. The method includes sending, by the coverage cell, an information about coverage cell load and carrier borrowing capabilities of an AAU of the coverage cell to the paired capacity

cells. The method includes determining, by each of the paired capacity cells, if a carrier shutdown entry condition of the capacity cell is met with a carrier borrowing by the coverage cell in accordance with the carrier borrowing capabilities. The method includes shutting down each of the paired capacity cells which carrier shutdown entry condition is determined to be met with the carrier borrowing. The method includes borrowing a carrier from one of the shutting down paired capacity cells by the coverage cell with using the AAU configuration of the capacity cell to activate the borrowed carrier, if it is determined by the coverage cell that a carrier borrowing condition is met.

The method increases shutting down time of the capacity cell by allowing neighboring coverage cell to borrow a carrier frequency of the capacity cell (e.g. in 4G and 5G networks), due to its relation with the paired coverage cell. By allowing the AAU of the coverage cell to borrow the carrier frequency of a shutting down capacity cell, the coverage cell capacity increases, thus enabling it to offload more traffic from the shutting down capacity cell. Then, the capacity cell may shutdown more often and for longer time, and may be re-activated less frequently. The AAU of the coverage cell may benefit from the shutdown carrier(s) of nearby AAUs of the capacity cell to increase their offloading capabilities and delay the activation of the capacity cells. The method enables the coverage cell to borrow and release the capacity cell channel in a transparent way. The method is semi-static and increases shutting down time of the capacity cell based on load measurement at the coverage cell and the paired capacity cell. The method selects the capacity and coverage cells under test, which are in different AAUs, and adjusts the traffic load in the capacity cell under inspection such that this capacity cell shuts down.

The method is energy efficient as the activation of the borrowed carrier at the AAU of the coverage cell only requires a slight increase in power consumption due to shared hardware between co-deployed carriers in the AAU. Further, the method requires a limited additional signaling exchange as the coverage cell acquires beforehand the capabilities and configuration of the paired capacity cells in terms of a number of carriers, their frequency, and bandwidth and informs its paired capacity cells about changes in the borrowing capabilities of its AAU.

Optionally, the carrier borrowing condition is met if a load of the coverage cell is above a pre-defined carrier borrowing activation threshold and below a pre-defined carrier shutdown leaving threshold. The carrier borrowing condition may depend on one or more of Key Performance Indicators, KPIs, of the coverage cell and/or the paired capacity cell, including a load, a number of connected User Equipment, UEs, coverage holes, cell rates, and cell delays.

Optionally, the method further includes releasing, by the coverage cell, the carrier borrowed from the shutdown paired capacity cell, when it is determined by the coverage cell that a carrier releasing condition is met. The method further includes re-borrowing, by the coverage cell, the carrier from the shutdown paired capacity cell, when it is determined by the coverage cell that the carrier borrowing condition is met.

Optionally, the carrier releasing condition is met if the mean of the coverage cell load at the borrowed carrier and the coverage cell load at its own carrier is below a pre-defined carrier borrowing releasing threshold.

Optionally, the method further includes determining, by the coverage cell, if a carrier shutdown leaving condition for the shutdown paired capacity cell is met. The method further includes sending, by the coverage cell, a cell activation message to activate the shutdown paired capacity cell for which carrier shutdown leaving condition is determined as met. The method further includes releasing the carrier borrowed by the coverage cell from the activated paired capacity cell.

Optionally, the carrier shutdown leaving condition is met if the mean of the coverage cell load at the borrowed carrier and the coverage cell load at its own carrier is above a pre-defined carrier shutdown leaving threshold. The carrier shutdown leaving condition may depend on one or more of KPIs of the coverage cell related to the borrowed carrier and/or its own carrier, including a load, a number of connected User Equipment, UEs, coverage holes, cell rate, and cell delay.

Optionally, the method further includes initiating an inter-frequency handover by the coverage cell to transfer any user equipment, UEs, connected to the coverage cell at the borrowed carrier to the own carrier of the coverage cell before sending the cell

activation message to the shutdown paired capacity cell. The sending of the cell activation message to activate the shutdown paired capacity cell includes (i) sending an AAU activation message by the coverage cell as the cell activation message to a Base Band Unit, BBU, of the shutdown paired capacity cell, (ii) activating the AAU of the shutdown paired capacity cell by the BBU, and (iii) conducting a mobility load balancing to balance the load between the own carrier of the coverage cell and the carrier borrowed by the coverage cell. The releasing of the carrier borrowed by the coverage cell includes releasing the borrowed carrier by the BBU of the coverage cell in response to receiving a confirmation from the BBU of the paired capacity cell that its AAU is activated, and the mobility load balancing is implemented.

Optionally, the method further includes determining, by the coverage cell, that the carrier shutdown leaving condition is met for a part of the borrowed carrier of the shutdown paired capacity cell. The method further includes suspending, by the coverage cell, the borrowed carrier from accepting new UE connections. The sending of the cell activation message to activate the shutdown paired capacity cell includes (i) sending by the coverage cell to a Base Band Unit, BBU, of the shutdown paired capacity cell a partial carrier activation message as the cell activation message, the partial carrier activation message indicating that the part of the capacity cell carrier is to be activated, and (ii) activating the part of the capacity cell carrier at the AAU of the shutdown paired capacity cell by the BBU. The releasing of the carrier borrowed by the coverage cell includes (i) transferring UEs connected to the coverage cell at the borrowed carrier to the activated part of the paired capacity cell carrier, and (ii) releasing the borrowed carrier by the coverage cell when its load is below a pre-defined coverage cell threshold for releasing carrier borrowing with sending a release message to the BBU of the partially activated paired capacity cell.

Optionally, the information about AAU configuration of each capacity cell includes a number of carriers owned by the capacity cell, frequencies, and bandwidths of the carriers. The information about carrier borrowing capabilities of an AAU of the coverage cell includes an information about available AAU slots at the AAU and processing resources of a Base Band Unit, BBU, of the AAU of the coverage cell.

Optionally, the method further includes defining a shutdown policy for each capacity cell of the multi-carrier cellular network. The shutdown policy includes a carrier shutdown entry condition and a carrier shutdown leaving condition. The carrier shutdown entry condition is met when a combined load of the capacity cell and the coverage cell is below a carrier shutdown threshold.

Optionally, the carrier shutdown threshold is defined during a pairing process of the coverage cell and the capacity cell as a function of a cell overlapping factor computed in a co-coverage analysis within the pairing process. Optionally, the method further includes initiating by the paired capacity cell an inter-frequency handover to the coverage cell before shutting down the paired capacity cell.

Optionally, the borrowing of the carrier from the shutdown paired capacity cell by the coverage cell includes (i) sending a carrier borrowing message by the coverage cell to a BBU of the shutdown paired capacity cell, (ii) allocating one slot of the AAU of the coverage cell to the borrowed carrier, and (iii) allocating processing resources of the BBU of the coverage cell to the allocated slot of the AAU.

Optionally, one of the capacity cells paired with the coverage cell is paired with one or more additional coverage cells and the method further includes coordinating the coverage cell with the additional coverage cells to enable only one of the co-paired coverage cells borrowing a carrier from the shutting down capacity cell.

Optionally, the coordinating of the coverage cell with the additional coverage cells includes enabling the one of the co-paired coverage cells that experiences a larger load and/or has a largest overlapping region with the shutting down capacity cell to borrow a carrier from the shutting down capacity cell.

Optionally, one of the capacity cells paired with the coverage cell is paired with one or more additional coverage cells and the method further includes enabling only one of the co-paired coverage cells to borrow a carrier from the shutting down capacity cell by the BBU of the shutting down capacity cell based on loads and/or other KPIs of the co-paired coverage cells.

Optionally, one of the capacity cells paired with the coverage cell is paired with one or more additional coverage cells and the method further includes splitting, by the BBU of the shutting down capacity cell, an available bandwidth in time of the carrier of the shutting down capacity cell into parts to be borrowed by different co-paired coverage cells. The splitting may be based on one or more of KPIs of the co-paired coverage cells, the KPIs including a load experienced by each of the co-paired coverage cells, an overlapping region of each of the co-paired coverage cells with the shutting down capacity cell and a latency of each of the co-paired coverage cells.

Therefore, in contradistinction to the existing solutions, the method increases shutting down time of the capacity cell by allowing neighboring coverage cell to borrow a carrier frequency of the capacity cell (e.g. in 4G and 5G networks), due to its relation with the paired coverage cell. By allowing the AAU of the coverage cell to borrow the carrier frequency of a shutting down capacity cell, the coverage cell capacity increases, thus enabling it to offload more traffic from the shutting down capacity cell. Then, the capacity cell may shutdown more often and for a longer time, and may be re-activated less frequently.

These and other aspects of the disclosure will be apparent from the implementation(s) described below.

BRIEF DESCRIPTION OF DRAWINGS

Implementations of the disclosure will now be described, by way of example only, with reference to the accompanying drawings, in which:

FIG. 1 illustrates a method for controlling carrier shutdowns in a multi-carrier cellular network for increasing a shutdown time of a capacity cell in accordance with an implementation of the disclosure;

FIG. 2 illustrates an exemplary interaction diagram of a capacity cell and a coverage cell in a multi-carrier cellular network for increasing a shutdown time of the capacity cell in accordance with an implementation of the disclosure;

FIG. 3 is a graphical representation that shows a load of a coverage cell of FIG. 2 in a multi-carrier cellular network during carrier shutdown, carrier borrowing, carrier

release, and carrier activation in accordance with an implementation of the disclosure;

FIG. 4 is an exemplary interaction diagram that illustrates a message sequence between a capacity cell and a coverage cell in a multi-carrier cellular network during a carrier shutdown with carrier borrowing in accordance with an implementation of the disclosure;

FIGS. 5A-5E illustrate exemplary views of a carrier shutdown/deactivation based on a load and multiple key performance indicators, KPIs, of a coverage cell in accordance with an implementation of the disclosure;

FIG. 6 illustrates an exemplary interaction diagram of a capacity cell paired with a coverage cell paired with one or more additional coverage cells in a multi-carrier cellular network for increasing a shutdown time of the capacity cell in accordance with an implementation of the disclosure; and

FIGS. 7A-7B are flow diagrams that illustrate a method of controlling carrier shutdowns in a multi-carrier cellular network in accordance with an implementation of the disclosure.

DETAILED DESCRIPTION OF THE DRAWINGS

Implementations of the disclosure provide a method of controlling carrier shutdowns in a multi-carrier cellular network.

To make solutions of the disclosure more comprehensible for a person skilled in the art, the following implementations of the disclosure are described with reference to the accompanying drawings.

Terms such as "a first", "a second", "a third", and "a fourth" (if any) in the summary, claims, and foregoing accompanying drawings of the disclosure are used to distinguish between similar objects and are not necessarily used to describe a specific sequence or order. It should be understood that the terms so used are interchangeable under appropriate circumstances, so that the implementations of the disclosure described herein are, for example, capable of being implemented in sequences other than the sequences illustrated or described herein. Furthermore, the terms "include" and "have"

and any variations thereof, are intended to cover a non-exclusive inclusion. For example, a process, a method, a system, a product, or a device that includes a series of steps or units, is not necessarily limited to expressly listed steps or units but may include other steps or units that are not expressly listed or that are inherent to such process, method, product, or device.

FIG. 1 illustrates a method for controlling carrier shutdowns in a multi-carrier cellular network for increasing a shutdown time of a capacity cell in accordance with an implementation of the disclosure. At a step **102**, a method for controlling carrier shutdowns in a multi-carrier cellular network is started. At a step **104**, an information about Active Antenna Unit, AAU, configuration of one or more capacity cells paired with a coverage cell in the multi-carrier cellular network is obtained by the coverage cell. At a step **106**, an information about coverage cell load and carrier borrowing capabilities of an AAU of the coverage cell is sent to the paired capacity cells by the coverage cell. At a step **108**, each of the paired capacity cells determines whether a carrier shutdown entry condition of the capacity cell is met with a carrier borrowing by the coverage cell in accordance with the carrier borrowing capabilities. If the carrier shutdown entry condition of the capacity cell is not met with the carrier borrowing by the coverage cell in accordance with the carrier borrowing capabilities, it repeats the step **108**. Else, it goes to a step **110** for shutting down each of the paired capacity cells which carrier shutdown entry condition is determined to be met with the carrier borrowing.

Optionally, the capacity cell implements a shutdown policy for shutting down each of the paired capacity cells which carrier shutdown entry condition is determined to be met with the carrier borrowing. Optionally, the method further includes initiating by the paired capacity cell an inter-frequency handover to the coverage cell before shutting down the paired capacity cell. At a step **112**, a carrier from one of the shutting down paired capacity cells is borrowed by the coverage cell with using the AAU configuration of the capacity cell to activate the borrowed carrier, if it is determined by the coverage cell that a carrier borrowing condition is met. At a step **114**, the coverage cell determines whether a carrier shutdown leaving condition for the shutdown paired capacity cell is met. If the carrier shutdown leaving condition is not met, it repeats the

step **114**. Else, it goes to a step **116** for sending a cell activation message by the coverage cell to activate the shutdown paired capacity cell which carrier shutdown leaving condition is determined as met, and the coverage cell releases the carrier borrowed from the activated paired capacity cell.

Optionally, the carrier borrowing condition is met if a load of the coverage cell is above a pre-defined carrier borrowing activation threshold and below a pre-defined carrier shutdown leaving threshold. The carrier borrowing condition may depend on one or more of Key Performance Indicators, KPIs, of the coverage cell and/or the paired capacity cell, including a load, a number of connected User Equipment, UEs, coverage holes, cell rates and cell delays. Optionally, the method further includes releasing, by the coverage cell, the carrier borrowed from the shutdown paired capacity cell, when it is determined by the coverage cell that a carrier releasing condition is met. The method further includes re-borrowing, by the coverage cell, the carrier from the shutdown paired capacity cell, when it is determined by the coverage cell that the carrier borrowing condition is met. Optionally, the carrier releasing condition is met if a mean of the coverage cell load at the borrowed carrier and the coverage cell load at its own carrier is below a pre-defined carrier borrowing releasing threshold.

Optionally, the carrier shutdown leaving condition is met if the mean of the coverage cell load at the borrowed carrier and the coverage cell load at its own carrier is above a pre-defined carrier shutdown leaving threshold. The carrier shutdown leaving condition may depend on one or more of KPIs of the coverage cell related to the borrowed carrier and/or its own carrier, including a load, a number of connected User Equipment, UEs, coverage holes, cell rate, and cell delay.

The AAU of the coverage cell may configure and use a new carrier in one of its unused AAU slots using the carrier of one of its paired shutdown capacity cells, and transmit using the same radio frequency, RF, configuration. When the carrier shutdown is active, the coverage cell sends to their capacity cells both load information and indications of the borrowing capabilities of their AAUs, i.e., the number of available unused slots in such an AAU frame, their operating frequency, etc. When carrier borrowing takes place at the AAU of the coverage cell, the carrier shutdown entry condition at the capacity cell may be relaxed using a larger carrier shutdown threshold. Thus, the capacity cell

may shutdown more often or for a longer time than without carrier borrowing, because the coverage cell may rely on the additional capacity provided by the borrowed carrier in its AAU.

An example of an AAU power model is illustrated given below:

$$P_{\mathrm{AAU}} = P_0 + P_{\mathrm{BB}} + \overbrace{\sum_{t=1}^{T} M_{\mathrm{av,t}} D_{\mathrm{TRX,t}}}^{P_{\mathrm{TRX}}} + \overbrace{M_{\mathrm{ac}} D_{\mathrm{PA}}}^{P_{\mathrm{PA}}} + \overbrace{\frac{1}{\eta} \sum_{c=1}^{C} P_{\mathrm{TX,c}}}^{P_{\mathrm{out}}},$$

where P_{AAU} is the power consumption of the active antenna unit, P_0 is the power consumption that accounts for part of the AAU circuitry that is always active (e.g., circuitry used to control the AAU activation/deactivation), P_{BB} is power consumption due to the baseband signal processing carried out at the AAU, P_{TRX} is the power consumption of the T transceivers of the AAU, P_{PA} is the power consumption of the M_{ac} power amplifiers, PA, and P_{out} is a power consumed to generate the transmit power required to transmit the data over the C carrier components.

In mode details, $P_{TRX,t,}$ the power consumed by each of the T transceivers in the AAU is the product of the number of available RF chains in the transceiver t, $M_{av,t}$, and the power consumed by each RF chain, $D_{TRX,t}$. The static power, P_{PA}, consumed by the multi-carrier PAs is the product of the number of active RF chains, M_{ac}, and the static power consumed by each multi-carrier PA, D_{PA}. Finally, P_{out} is computed as the ratio between the sum of the output power at each of the C carrier components, $P_{TX,c}$ and the efficiency of the multi-carrier PA and antenna η.

The method is energy efficient as the activation of the borrowed carrier at the AAU of the coverage cell only requires a slight increase in power consumption due to shared hardware between co-deployed carriers in the AAU. Further, the method requires a limited additional signaling exchange as the coverage cell acquires beforehand the capabilities and configuration of the paired capacity cells in terms of a number of carrier, their frequency, and bandwidth and informs its paired capacity cells about changes in the borrowing capabilities of its AAU.

The method increases the shutting down time of the capacity cell by allowing neighboring coverage cell to borrow a carrier frequency of the capacity cell (e.g. in 4G and 5G networks), due to its relation with the paired coverage cell. By allowing the AAU of the coverage cell to borrow the carrier frequency of a shutting down capacity cell, the coverage cell capacity increases, thus enabling it to offload more traffic from the shutting down capacity cell. Then, the capacity cell may shutdown more often and for longer time, and may be re-activated less frequently. The AAU of the coverage cell may benefit from the shutdown carrier(s) of nearby AAUs of the capacity cell to increase their offloading capabilities and delay the activation of the capacity cells. The method enables the coverage cell to borrow and release the capacity cell channel in a transparent way. The method is semi-static and increases the shutting down time of the capacity cell based on load measurement at the coverage cell and the paired capacity cell. The method selects the capacity and coverage cells under test, which are in different AAUs and adjusts the traffic load in the capacity cell under inspection such that this capacity cell shuts down.

FIG. 2 illustrates an exemplary interaction diagram of a capacity cell **202** and a coverage cell **204** in a multi-carrier cellular network for increasing a shutdown time of the capacity cell **204** in accordance with an implementation of the disclosure. In the multi-carrier cellular network, Active Antenna Units, AAUs, of multiple-carriers are deployed to attain a balance between the coverage cell **204** and the capacity cell **202** requirements. At a step **206**, the capacity cell **202** and the coverage cell **204** in the multi-carrier cellular network is paired according to a co-coverage analysis. At a step **208**, an information about AAU configuration is sent to the paired coverage cell **204** by the capacity cell **202**. Optionally, the information about AAU configuration of each capacity cell **202** includes a number of carriers owned by the capacity cell **202**, frequencies, and bandwidths of the carriers.

At a step **210**, a shutdown policy is defined for each capacity cell **202** of the multi-carrier cellular network. Optionally, the shutdown policy includes a carrier shutdown entry condition and a carrier shutdown leaving condition. The carrier shutdown entry condition is met when a combined load of the capacity cell **202** and the coverage cell **204** is below a carrier shutdown threshold. Optionally, the carrier shutdown entry

condition depends on whether carrier borrowing is possible at the AAU of the coverage cell **204**. Optionally, the carrier shutdown threshold considers the capacity of the coverage cell **204** with/without carrier borrowing. Optionally, the carrier shutdown threshold is defined to activate/release the borrowed carrier at the AAU of the coverage cell **204**. Optionally, the carrier shutdown threshold is defined during a pairing process of the coverage cell **204** and the capacity cell **202** as a function of a cell overlapping factor computed in the co-coverage analysis within the pairing process. At a step **212**, the shutdown policy for each capacity cell **202** of the multi-carrier cellular network is activated. Optionally, the shutdown policy runs during a pre-defined interval. At a step **214**, an information about the coverage cell load and carrier borrowing capabilities of the AAU of the coverage cell **204** is sent by the coverage cell **204** to the paired capacity cell **202**. Optionally, the information about carrier borrowing capabilities of the AAU of the coverage cell **204** includes an information about available AAU slots at the AAU and processing resources of a Base Band Unit, BBU, of the AAU of the coverage cell **204**. At a step **216**, the paired capacity cell **202** determines whether the carrier shutdown entry condition of the capacity cell **202** is met with a carrier borrowing by the coverage cell **204** in accordance with the carrier borrowing capabilities and the paired capacity cell **202** which carrier shutdown entry condition is determined to be met with the carrier borrowing is shut down. At a step **218**, a status message including an information about the shutting down of the paired capacity cell **202** is sent to the coverage cell **204** by the capacity cell **202**. Optionally, the capacity cell **202** to be shutdown operates an inter-frequency handover, as in a baseline carrier shutdown scheme, to realize the offloading.

At a step **220**, a carrier from the shutting down paired capacity cell **202** is borrowed by the coverage cell **204** with using the AAU configuration of the capacity cell **202** to activate the borrowed carrier, if it is determined, by the coverage cell **204**, that a carrier borrowing condition is met by sending a carrier borrowing message to the BBU of the shutdown paired capacity cell **202** at a step **222**. Optionally, the carrier borrowing condition is met if a load of the coverage cell **204** is above a pre-defined carrier borrowing activation threshold and below a pre-defined carrier shutdown leaving threshold. Optionally, the carrier borrowing condition depends on one or more of Key Performance Indicators, KPIs, of the coverage cell **204** and/or the paired capacity cell

202, including a load, a number of connected User Equipment, UEs, coverage holes, cell rates and cell delays. At a step **224**, the borrowed carrier of the paired capacity cell **202** is released when the load at the coverage cell **204** decreases below a pre-defined coverage cell threshold.

At a step **226**, the borrowed carrier from the shutdown paired capacity cell **202** is released by the coverage cell **204**, when it is determined by the coverage cell **204** that a carrier releasing condition is met. Optionally, the carrier releasing condition is met if the mean of the coverage cell load at the borrowed carrier and the coverage cell load at its own carrier is below a pre-defined carrier borrowing releasing threshold. Optionally, the coverage cell **204** re-borrows the carrier from the shutdown paired capacity cell **202**, when it is determined by the coverage cell **204** that the carrier borrowing condition is met. At a step **228**, the borrowed carrier is activated by the AAU of the coverage cell **204** when the load at the coverage cell **204** increases, and a carrier shutdown leaving condition for the shutdown paired capacity cell **202** is met. At a step **230**, the coverage cell **204** sends a cell activation message including the information about the activation of the borrowed carrier of the shutdown paired capacity cell **202** to the shutdown paired capacity cell **202** which carrier shutdown leaving condition is determined as met. At a step **232**, the carrier borrowed by the coverage cell **204** is activated at the paired capacity cell **202** by the coverage cell **204**.

FIG. 3 is a graphical representation that shows a load of a coverage cell **204** of FIG. 2 in a multi-carrier cellular network during carrier shutdown, carrier borrowing, carrier release, and carrier activation in accordance with an implementation of the disclosure. From the graphical representation, it is observed that the sum load of both the coverage cell **204** and the capacity cell **202** is below the carrier shutdown entry condition during the carrier borrowing and the carrier release. If the sum load of both the coverage cell **204** and the capacity cell **202** is below the carrier shutdown entry condition, the paired capacity cell **202** initiates an inter-frequency handover and if the inter-frequency handover is successfully completed, the paired capacity cell **202** is shut down. If the coverage cell's **204** capacity increases, it enables offloading more traffic from the shutting down capacity cell **202**. Then, the capacity cell **202** may shutdown more often and for a longer time, and may be re-activated less frequently.

FIG. 4 is an exemplary interaction diagram that illustrates a message sequence between a capacity cell **402** and a coverage cell **404** in a multi-carrier cellular network during a carrier shutdown with carrier borrowing in accordance with an implementation of the disclosure. In the multi-carrier cellular network, multi carrier Active Antenna Units, AAUs, are deployed to attain a balance between the coverage cell **404** and capacity cell **402** requirements. The carrier borrowing enables the coverage cell **404** associated with the capacity cell **402** that is shutting down to borrow its carrier/bandwidth in order to momentaneously increase the coverage cell capacity, such that coverage cell **404** can smoothly support the additional load carried out by any user equipment, UEs, previously served by the shutting down capacity cell **402**. The carrier borrowing may improve the quality of service at the user equipment's side and it may extend the shutting down time of the capacity cell **402**, which needs to be activated when the associated coverage cell load increases above a pre-defined threshold.

At a step **406**, the capacity cell **402** and the coverage cell **404** in the multi-carrier cellular network are paired according to a co-coverage analysis. At a step **408**, an information about AAU configuration is sent with the paired coverage cell **404** by the capacity cell **402**. Optionally, the exchange of information is realized between Base Band Units, BBUs of the capacity cell **402** and the paired coverage cell **404**. Optionally, the information about AAU configuration of each capacity cell **402** includes a number of carriers owned by the capacity cell **402**, frequencies and bandwidths of the carriers. At a step **410**, a shutdown policy is defined for each capacity cell **402** of the multi-carrier cellular network. Optionally, the shutdown policy includes a carrier shutdown entry condition, a carrier shutdown leaving condition, and a time at which the shutdown policy starts and ends. The carrier shutdown entry condition is met when a combined load of the capacity cell **402** and the coverage cell **404** is below a carrier shutdown threshold. Optionally, the carrier shutdown threshold is defined during a pairing process of the coverage cell **404** and the capacity cell **402** as a function of a cell overlapping factor computed in the co-coverage analysis within the pairing process.

Optionally, the carrier shutdown threshold is denoted as:

- th_{off} - carrier shutdown threshold (i.e. capacity cell threshold) for the carrier shutdown entry condition without carrier borrowing;

- th_{on} - carrier shutdown threshold (i.e. capacity cell threshold) for the carrier shutdown leaving condition without carrier borrowing;
- $\overline{th_{\text{off}}}$ - carrier shutdown threshold (i.e. capacity cell threshold) for the carrier shutdown entry condition with carrier borrowing;
- $\overline{th_{on}}$ - carrier shutdown threshold (i.e. capacity cell threshold) for the carrier shutdown leaving condition with carrier borrowing;
- th'_{off} - a pre-defined coverage cell threshold for releasing carrier borrowing;
- th'_{on} - a pre-defined coverage cell threshold for activating carrier borrowing.

In addition, the followings are denoted as:

- $\lambda_{\text{cov.}}$ - coverage cell load;
- $\lambda_{\text{cap.}}$ - capacity cell load;
- $\lambda_{bor.}$ - load of the capacity cell's **402** carrier borrowed at the coverage cell **404**.

At a step **412**, the shutdown policy for each capacity cell **402** of the multi-carrier cellular network is activated. Optionally, the shutdown policy runs during a pre-defined interval. Optionally, during a running time of the shutdown policy, the paired capacity cell **402** periodically requests information about load and carrier borrowing capabilities (i.e. the configuration and a load status, for example, the coverage cell load, $\lambda_{\text{cov.}}$) of the paired coverage cell **404**. At a step **414**, an information about the coverage cell load and carrier borrowing capabilities of an AAU of the coverage cell **404** is sent by the coverage cell **404** to the paired capacity cell **402**. Optionally, the information about carrier borrowing capabilities of an AAU of the coverage cell **404** includes an information about available AAU slots at the AAU and processing resources of a Base Band Unit, BBU, of the AAU of the coverage cell **404**. Optionally, the AAU of the coverage cell may or may not be compatible with a carrier frequency used at the capacity cell **402**.

Optionally, if the shutdown policy is active, the capacity cell **402** may get shutdown based on the information about coverage cell load, a capacity cell load, and the carrier borrowing capabilities of the AAU of the coverage cell **404**.

At a step **416**, the paired capacity cell **402** determines whether the carrier shutdown entry condition of the capacity cell **402** is met with a carrier borrowing by the coverage

cell **404** in accordance with the carrier borrowing capabilities. If the carrier shutdown entry condition of the capacity cell **402** is met with the carrier borrowing by the coverage cell **404** (e.g. if the sum load of both the coverage cell **404** and the capacity cell **402** is below the carrier shutdown entry condition with the carrier borrowing, $\lambda_{\text{cov.}}+\lambda_{\text{cap.}} < \overline{th_{\text{off}}}$), the paired capacity cell **402** initiates an inter-frequency handover and if the inter-frequency handover is successfully completed, the paired capacity cell **402** is shut down. At a step **418**, when the AAU of the paired capacity cell **402** is shutdown/deactivated, its BBU sends a status message to the coverage cell **404** to shutdown/deactivate the computational resources allocated for the capacity cell **402**. Optionally, at the BBU of the capacity cell **402**, only a few processing resources are maintained to receive and process control messages from the network, e.g. the paired coverage cell **404**.

Optionally, while the capacity cell **402** is shutdown/deactivated, its coverage cell **404** continuously measures its load status and compares the results with a carrier shutdown leaving condition and a pre-defined carrier borrowing activation threshold. Optionally, the carrier borrowing condition is met if a load of the coverage cell is above the pre-defined carrier borrowing activation threshold and below a pre-defined carrier shutdown leaving threshold. Optionally, the carrier borrowing condition depends on one or more of Key Performance Indicators, KPIs, of the coverage cell **404** and/or the paired capacity cell **402**, including a load, a number of connected User Equipment, UEs, coverage holes, cell rates and cell delays. At a step **420**, if the coverage cell's **404** load is larger than/above the pre-defined carrier borrowing activation threshold, $\lambda_{\text{cov.}} > th'_{on}$, and smaller than/below the pre-defined carrier shutdown leaving condition, $\lambda_{\text{cov.}} < th_{on}$, the coverage cell **404** generates a carrier borrowing message to borrow the carrier of the shutdown capacity cell **402**. At a step **422**, the coverage cell **404** sends a carrier borrowing message to the BBU of the shutdown paired capacity cell **402** and borrows the carrier of the shutdown capacity cell **402**. Optionally, one slot of the AAU of the coverage cell **404** is allocated to the borrowed carrier and the BBU of the coverage cell **404** allocates processing resources to the allocated slot of the AAU.

Optionally, the carrier shutdown leaving condition is met if the mean of the coverage cell load at the borrowed carrier and the coverage cell load at its own carrier is above a

pre-defined carrier shutdown leaving threshold. The carrier shutdown leaving condition may depend on one or more of KPIs of the coverage cell **404** related to the borrowed carrier and/or its own carrier, including a load, a number of connected User Equipment, UEs, coverage holes, cell rate, and cell delay.

At a step **424**, while the capacity cell **402** is still shutdown/deactivated, if the coverage cell load, which can be computed as the mean of the load at the capacity cell borrowed carrier and the load at its original carrier, is larger than/above the carrier shutdown leaving condition with carrier borrowing, $\frac{\lambda_{\text{cov.}}+\lambda_{\text{bor.}}}{2} > \overline{th_{on}}$, the coverage cell **404**, initiates an inter-frequency handover to transfer any user equipment, UEs, connected to the coverage cell **404** at the borrowed carrier to the own carrier of the coverage cell **404** before sending the cell activation message to the shutdown paired capacity cell **402**. At a step **426**, the coverage cell **404** sends an AAU activation message as the cell activation message to the Base Band Unit, BBU, of the shutdown paired capacity cell **402**. At a step **428**, the BBU of the capacity cell **402** activates the AAU of the shutdown paired capacity cell **402**. At a step **430**, the BBU of the capacity cell **402** confirms the carrier activation to the coverage cell **404** and accordingly part of the users attached to the coverage cell **404** handover to the capacity cell **402** thus balancing the load between the own carrier of the coverage cell **404** and the activated carrier at the capacity cell **402**. At a step **432**, the BBU of the coverage cell **404** releases the carrier borrowed. Optionally, the carrier borrowed is released by the BBU of the coverage cell **404** in response to receiving a confirmation from the BBU of the paired capacity cell **402** that its AAU is activated, and the mobility load balancing is implemented.

Optionally, the coverage cell **404** determines that the carrier shutdown leaving condition is met for a part of the borrowed carrier of the shutdown paired capacity cell **402**. The coverage cell **404** suspends the borrowed carrier from accepting new UE connections. The sending of the cell activation message to activate the shutdown paired capacity cell **402** includes (i) sending by the coverage cell **404** to a Base Band Unit, BBU, of the shutdown paired capacity cell **402** a partial carrier activation message indicating that the part of the capacity cell carrier is to be activated as the cell activation message, and (ii) activating the part of the capacity cell carrier at the AAU of the shutdown paired capacity cell **402** by the BBU. The releasing of the carrier borrowed by the coverage

cell **404** includes (i) transferring UEs connected to the coverage cell **404** at the borrowed carrier to the activated part of the paired capacity cell carrier, and (ii) releasing the borrowed carrier by the coverage cell **404** when its load is below a pre-defined coverage cell threshold for releasing carrier borrowing with sending a release message to the BBU of the partially activated paired capacity cell **402**.

Optionally, when the carrier borrowing is implemented, the coverage cell **404** is associated with activating and releasing a pre-defined carrier borrowing activation threshold and a pre-defined carrier borrowing releasing threshold (i.e. carrier borrowing thresholds). The pre-defined carrier borrowing activation threshold is used at the coverage cell **404** to determine whether to borrow a carrier of the paired capacity cell **402** and the pre-defined carrier borrowing releasing threshold is used to release the borrowed carrier. Optionally, the carrier shutdown entry condition and the carrier shutdown leaving condition with carrier borrowing are determined by each of the paired capacity cells **402**.

Optionally, when the capacity cell **402** is deactivated/shutdown, and the coverage cell **404** borrows the capacity cell's **402** carrier, the coverage cell **404** may dynamically release and activate the borrowed carrier to reduce its power consumption. Specifically, if the coverage cell's **404** load, which is the mean of the load at the capacity cell borrowed carrier and the load at its original carrier, is below the pre-defined coverage cell threshold th'_{off}, for releasing carrier borrowing, $\frac{\lambda_{\text{cov.}}+\lambda_{bor.}}{2} < th'_{\text{off}}$, the BBU of the coverage cell **404** releases the borrowed carrier of the capacity cell **402**. Optionally, if the coverage cell's **404** load becomes larger than/above the pre-defined carrier borrowing activation threshold, $\lambda_{\text{cov.}} > th'_{on}$, and its load is smaller than/below the pre-defined carrier shutdown leaving condition, $\lambda_{\text{cov.}} < th_{on}$, the BBU of the coverage cell **404** re-activate the borrowed carrier of the shutdown capacity cell **402**.

Optionally, the carrier shutdown threshold is defined for the carrier shutdown entry condition with carrier borrowing, $\overline{th_{\text{off}}}$, as follows:

$\overline{th_{\text{off}}} = th_{\text{off}} + \omega\lambda_{\text{cap.}}$, where $0 < \omega < 1$ is a cell overlapping factor.

Optionally, the carrier shutdown threshold is defined during the pairing process of the coverage cell **404** and the capacity cell **402** as a function of the cell overlapping factor computed in a co-coverage analysis within the pairing process. Optionally, since the carrier shutdown threshold for the carrier shutdown entry condition with carrier borrowing is above the carrier shutdown threshold for the carrier shutdown entry condition without carrier borrowing, $\overline{th_{\text{off}}} > th_{\text{off}}$, the capacity cell **402** may shutdown more often when the carrier borrowing mechanism is implemented.

Optionally, the carrier shutdown threshold is defined for the carrier shutdown leaving condition with carrier borrowing, $\overline{th_{\text{on}}}$, as follows:

$$\overline{th_{\text{on}}} = th_{\text{on}}$$

Optionally, the coverage cell **404** activates the capacity cell **402** without a carrier borrowing when the coverage cell load is larger than the carrier shutdown threshold for the carrier shutdown leaving condition, $\lambda_{\text{cov.}} > th_{on}$. The carrier shutdown leaving condition with a carrier borrowing may be defined as $\frac{\lambda_{\text{cov.}}+\lambda_{bor.}}{2} > \overline{th_{\text{on}}} \rightarrow \lambda_{\text{cov.}}+\lambda_{bor.} > 2\overline{th_{\text{on}}} \rightarrow \lambda_{\text{cov.}}+\lambda_{bor.} > 2th_{\text{on}}$. The capacity cell **402** can shutdown for longer when the carrier borrowing mechanism is implemented as part of the coverage cell load may be transferred to the borrowed carrier.

Optionally, the pre-defined coverage cell threshold is defined for releasing carrier borrowing th'_{off} as follows:

$$th'_{\text{off}} = th_{\text{off}}$$

Optionally, the pre-defined coverage cell threshold is defined for activating carrier borrowing th'_{on} as follows:

$$th'_{\text{on}} = th'_{\text{off}} + \Delta,$$

where $\Delta > 0$ can be computed as $\Delta = th_{\text{off}} - th_{on}$.

Optionally, while the capacity cell **402** is still deactivated/shutdown and the mean of the coverage cell load at the borrowed carrier and the coverage cell load at its own carrier is

above the pre-defined carrier shutdown leaving threshold, $\frac{\lambda_{\text{cov.}}+\lambda_{\text{bor.}}}{2} > \overline{th_{on}}$, the coverage cell **404** (i) suspends the borrowed carrier from accepting new UE connections, (ii) sends, to the Base Band Unit, BBU, of the shutdown paired capacity cell **402**, a partial carrier activation message indicating that the part of the capacity cell carrier is to be activated as the cell activation message, and activates the part of the capacity cell carrier at the AAU of the shutdown paired capacity cell **402** by the BBU, (iii) transfers the UEs connected to the coverage cell **404** at the borrowed carrier to the activated part of the paired capacity cell carrier, (iv) releases the borrowed carrier when the coverage cell load is below the pre-defined coverage cell threshold, th'_{off}, for releasing carrier borrowing with sending a release message to the BBU of the partially activated paired capacity cell **402**, and (v) sends a release message to the BBU of the capacity cell **402**. The coverage cell releases the borrowed carrier when its load becomes lower than th_{off}.

FIGS. 5A-5E illustrate exemplary views of a carrier shutdown/deactivation based on a load and multiple key performance indicators, KPIs, of a coverage cell **504** in accordance with an implementation of the disclosure. In a multi-carrier cellular network, cells are divided into capacity cells and coverage cells to enable an energy saving policy. The carrier borrowing may improve the quality of service at the user equipment's side and it may extend the shutting down time of the capacity cell **502**, which needs to be activated when the associated coverage cell load increases above a pre-defined threshold. The capacity cell **502** and the coverage cell **504** in the multi-carrier cellular network is paired according to a co-coverage analysis. Optionally, an information about AAU configuration is sent with the paired coverage cell **504** by the capacity cell **502**. Optionally, the information about AAU configuration of the capacity cell **502** includes a number of carriers owned by the capacity cell **502**, frequencies, and bandwidths of the carriers. Optionally, a shutdown policy is defined for each capacity cell **502** of the multi-carrier cellular network. Optionally, the shutdown policy includes a carrier shutdown entry condition, a carrier shutdown leaving condition, and a time at which the shutdown policy starts and ends. The carrier shutdown entry condition is met when a combined load of the capacity cell **502** and the coverage cell **504** is below a carrier shutdown threshold. Optionally, the carrier shutdown threshold is defined during

a pairing process of the coverage cell **504** and the capacity cell **502** as a function of a cell overlapping factor computed in the co-coverage analysis within the pairing process.

Optionally, the carrier shutdown threshold is denoted as:

- th_{off} - carrier shutdown_threshold (i.e. capacity cell threshold) for the carrier shutdown entry condition without carrier borrowing;
- th_{on} - carrier shutdown_threshold (i.e. capacity cell threshold) for the carrier shutdown leaving condition without carrier borrowing;
- $\overline{th_{\text{off}}}$ - carrier shutdown_threshold (i.e. capacity cell threshold) for the carrier shutdown entry condition with carrier borrowing;
- $\overline{th_{on}}$ - carrier shutdown_threshold (i.e. capacity cell threshold) for the carrier shutdown leaving condition with carrier borrowing;
- th'_{off} - a pre-defined coverage cell threshold for releasing carrier borrowing;
- th'_{on} - a pre-defined coverage cell threshold for activating carrier borrowing.

In addition, the followings are denoted as:

- $\lambda_{\text{cov.}}$ - coverage cell load;
- $\lambda_{\text{cap.}}$ - capacity cell load;
- $\lambda_{\text{bor.}}$ - load of the capacity cell's **502** carrier borrowed at the coverage cell **504**.

FIG. 5A shows that the capacity cell **502** operates, a carrier, f_{cap}, and the coverage cell **504** operates a carrier, f_{cov}. For example, $(f_{cap} = 2.6\text{GHz}; B_{cap} = 20\ \text{MHz})$ and $(f_{cov} = 1.8\ \text{GHz};\ ; B_{cov} = 10\ \text{MHz})$ and the power consumption of both the coverage cell **504** and the capacity cell **502**, P_{sum}, is ≈ 1450 Watts.

Optionally, if the shutdown policy is active, the capacity cell **502** may shutdown based on the information about coverage cell load, a capacity cell load and the carrier borrowing capabilities of the AAU of the coverage cell **504**. The carrier borrowing of the coverage cell **504** from the paired capacity cell **502** is depicted in FIG. 5B. The AAU of the coverage cell **504** borrows the capacity cell carrier, $f_{bor.}$, if the carrier shutdown entry condition of the capacity cell **502** is met with the carrier borrowing by the coverage cell **504**. Here, th_{off} is replaced by $\overline{th_{\text{off}}} > th_{\text{off}}$, i.e. $\lambda_{\text{cap.}}+\lambda_{\text{cov.}} < \overline{th_{\text{off}}}$. Optionally, the_carrier shutdown threshold, $\overline{\text{th}_{\text{off}}}$, is defined for the carrier shutdown

entry condition with carrier borrowing as $\overline{th_{off}} = th_{off} + \omega\lambda_{cap.}$, where $0 < \omega < 1$ is a cell overlapping factor. Optionally, when the coverage cell **504** borrows carrier from the paired capacity cell **502** as shown in FIG. 5B, the power consumption of both the coverage cell **504** and the capacity cell **502**, $P_{sum,}$ is 1160W, i.e. 20% of power saved when compared with the power consumption of both the coverage cell **504** and the capacity cell **502** of FIG. 5A.

The carrier releasing of the borrowed carrier of the capacity cell **502** by the coverage cell **504** is depicted in FIG. 5C. Optionally, when the capacity cell **502** is deactivated/shutdown, and the coverage cell **504** is borrowed the capacity cell carrier, it may dynamically release and activate the borrowed carrier to reduce its power consumption at a base station and a user equipment, UE, sides. Specifically, if the load of the coverage cell **504**, which is the mean of the load at the capacity cell's **502** borrowed carrier and the load at its original carrier, is below the pre-defined coverage cell threshold, th'_{off}, for releasing carrier borrowing, i.e. $\frac{\lambda_{cov.}+\lambda_{bor.}}{2} < th'_{off}$, the AAU of the coverage cell **504** releases the borrowed carrier of the capacity cell **502**. Optionally, the pre-defined coverage cell threshold for releasing carrier borrowing is equal to the carrier shutdown_threshold (i.e. capacity cell threshold) for the carrier shutdown entry condition without carrier borrowing , i. e. $th'_{off} = th_{off}$. Optionally, the power consumption of both the coverage cell **504** and the capacity cell **502**, $P_{sum,}$ is 1060W, i.e. 27% of power saved when compared with the power consumption of both the coverage cell **504** and the capacity cell **502** of FIG. 5A.

The re-activating of the borrowed carrier of the capacity cell **502** by the coverage cell **504** is depicted in FIG. 5D. Optionally, when the coverage cell load becomes larger than/above the pre-defined carrier borrowing activation threshold, i.e. the AAU of the coverage cell **504** re-activates the borrowed carrier of the shutdown capacity cell **502**. Optionally, the pre-defined coverage cell threshold for activating carrier borrowing is equal to the carrier shutdown_threshold (i.e. capacity cell threshold) for the carrier shutdown leaving condition without carrier borrowing, i.e. $th'_{on} = th_{on}$. Optionally, the power consumption of both the coverage cell **504** and the capacity cell **502**,

$P_{\text{sum,}}$ is 1160W, i.e. 20% of power saved when compared with the power consumption of both the coverage cell **504** and the capacity cell **502** of FIG. 5A.

The sending of a cell activation message to the capacity cell **502** by the coverage cell **504** is depicted in FIG. 5E. Optionally, while the capacity cell **502** is still deactivated/shutdown and the mean of the coverage cell load at the borrowed carrier and the coverage cell load at its own carrier is above the pre-defined carrier shutdown leaving threshold, i.e. $\frac{\lambda_{\text{cov.}}+\lambda_{\text{bor.}}}{2} > \overline{th_{on}}$, where $\overline{th_{on}} > \overline{th_{\text{off}}} > th_{on}$, the coverage cell **504** sends a cell activation message to the paired capacity cell **502**, and releases the borrowed carrier. Optionally, the carrier shutdown_threshold for the carrier shutdown leaving condition with carrier borrowing is equal to carrier shutdown_threshold (for the carrier shutdown entry condition with carrier borrowing, i.e. $\overline{th_{on}} = \overline{th_{\text{off}}} + \Delta$, where, $\Delta = th_{\text{off}} - th_{on}$. Optionally, the power consumption of both the coverage cell **504** and the capacity cell **502**, $P_{\text{sum,}}$ is 1450W.

Optionally, the carrier borrowing condition is met if a load of the coverage cell **504** is above a pre-defined carrier borrowing activation threshold and below a pre-defined carrier shutdown leaving threshold. The carrier borrowing condition may depend on one or more of Key Performance Indicators, KPIs, of the coverage cell and/or the paired capacity cell, including a load, a number of connected User Equipment, UEs, coverage holes, cell rates, and cell delays. For example, if $\frac{\lambda_{\text{cov.}}+\lambda_{\text{bor.}}}{2} < th'_{\text{off}}$, the AAU of the coverage cell **504** does not release the borrowed carrier when $N_{UE,\,\text{cov.}} + N_{UE,\text{bor.}} > th_{\text{UE}}$, where $N_{UE,\,\text{cov.}}$, $N_{UE,\text{bor.}}$ are the number of UEs in connected mode in the coverage cell **504** original and borrowed carrier respectively, and th_{UE} is an priori defined threshold. Optionally, the AAU of the coverage cell **504** reactivates the borrowed carrier even if $\lambda_{\text{cov.}} < th'_{on}$, as the $R_{\text{cov.}} < th_{\text{rate}}$, where $R_{\text{cov.}}$ is the rate experienced at the coverage cell **504** and th_{rate} is the priori defined threshold. Optionally, the KPIs, of the coverage cell **504** are used in a linear combination to determine whether the borrowed carrier should be activated or released.

FIG. 6 illustrates an exemplary interaction diagram of a capacity cell **602** paired with a coverage cell **604A** is paired with one or more additional coverage cells **604B** in a

multi-carrier cellular network for increasing a shutdown time of the capacity cell **602** in accordance with an implementation of the disclosure. At a step **606**, the capacity cell **602** paired with the coverage cell **604A** is paired with one or more additional coverage cells **604B** in the multi-carrier cellular network according to a co-coverage analysis. At a step **608**, an information about AAU configuration is sent to the co-paired coverage cells (**604A-604B**) by the capacity cell **602**. Optionally, the information about AAU configuration of each capacity cell **602** includes a number of carriers owned by the capacity cell **602**, frequencies and bandwidths of the carriers. At a step **610**, a shutdown policy is defined for each capacity cell **602** of the multi-carrier cellular network. Optionally, the shutdown policy includes a carrier shutdown entry condition and a carrier shutdown leaving condition. The carrier shutdown entry condition is met when a combined load of the capacity cell **602** and the co-paired coverage cells (**604A-604B**) is below a carrier shutdown threshold. Optionally, the carrier shutdown threshold is defined during a pairing process of the co-paired coverage cells (**604A-604B**) and the capacity cell **602** as a function of a cell overlapping factor computed in the co-coverage analysis within the pairing process.

At a step **612**, the shutdown policy for each capacity cell **602** of the multi-carrier cellular network is activated. Optionally, the shutdown policy runs during a pre-defined interval. At a step **614**, an information about the coverage cell's load and carrier borrowing capabilities of the AAU of the co-paired coverage cells (**604A-604B**) is sent by the co-paired coverage cells (**604A-604B**) to the paired capacity cell **602**. Optionally, the information about carrier borrowing capabilities of the AAU of the co-paired coverage cells (**604A-604B**) includes an information about available AAU slots at the AAU and processing resources of a Base Band Unit, BBU, of the AAU of the co-paired coverage cells (**604A-604B**).

At a step **616**, the paired capacity cell **602** determines whether the carrier shutdown entry condition of the capacity cell **602** is met with a carrier borrowing by any one of the co-paired coverage cells (**604A-604B**) in accordance with the carrier borrowing capabilities and the paired capacity cell **602** which carrier shutdown entry condition is determined to be met with the carrier borrowing is shut down. At a step **618**, a status message including an information about the shutting down of the paired capacity cell

602 is sent to the co-paired coverage cells (**604A-604B**) by the capacity cell **602**. At a step **620,** the coverage cell **604A** coordinates with the additional coverage cells **604B** to enable only one of the co-paired coverage cells (**604A-604B**) to borrow a carrier from the shutting down capacity cell **602** to optimize network performance. Optionally, the coordinating of the coverage cell **604A** with the additional coverage cells **604B** includes enabling the one of the co-paired coverage cells (**604A-604B**) that experiences a larger load and/or has a largest overlapping region with the shutting down capacity cell **602** to borrow a carrier from the shutting down capacity cell **602**. Optionally, one of the capacity cells **602** paired with the coverage cell **604A** is paired with one or more additional coverage cells **604B** enables only one of the co-paired coverage cells (**604A-604B**) to borrow a carrier from the shutting down capacity cell **602** by the BBU of the shutting down capacity cell **602** based on loads and/or other KPIs of the co-paired coverage cells (**604A-604B**).

At a step **622**, a carrier from the shutting down paired capacity cell **602** is borrowed by only one of the co-paired coverage cells (**604A-604B**) using the AAU configuration of the capacity cell **602** to activate the borrowed carrier, if it is determined, by one of the co-paired coverage cells (**604A-604B**), that a carrier borrowing condition is met. Optionally, the carrier borrowing condition is met if a load of one of the co-paired coverage cells (**604A-604B**) is above a pre-defined carrier borrowing activation threshold and below a pre-defined carrier shutdown leaving threshold. Optionally, the carrier borrowing condition depends on one or more of Key Performance Indicators, KPIs, of the co-paired coverage cells (**604A-604B**) and/or the paired capacity cell **602**, including a load, a number of connected User Equipment, UEs, coverage holes, cell rates and cell delays.

At a step **624**, one of the co-paired coverage cells (**604A-604B**) which borrows the carrier sends a carrier borrowing message to the BBU of the shutdown paired capacity cell **602**. Optionally, one slot of the AAU of one of the co-paired coverage cells (**604A-604B**) is allocated to the borrowed carrier, and the BBU of one of the co-paired coverage cells (**604A-604B**) allocates processing resources to the allocated slot of the AAU. At a step **626**, the carrier of the paired capacity cell **602** is released when the load at one of the co-paired coverage cells (**604A-604B**) decreases. At a step **628**, the carrier

borrowed from the shutdown paired capacity cell **602** is released by one of the co-paired coverage cells (**604A-604B**), when it is determined by one of the co-paired coverage cells (**604A-604B**) that a carrier releasing condition is met. Optionally, the carrier releasing condition is met if the mean of the co-paired coverage cells load at the borrowed carrier and the co-paired coverage cell load at its own carrier is below a pre-defined carrier borrowing releasing threshold. Optionally, one of the co-paired coverage cell (**604A-604B**) re-borrows the carrier from the shutdown paired capacity cell **602**, when it is determined by any one of the co-paired coverage cell (**604A-604B**) that the carrier borrowing condition is met.

Optionally, one of the capacity cells **602** paired with the coverage cell **604A** is paired with one or more additional coverage cells **604B** and the BBU of the shutting down capacity cell **602** splits an available bandwidth in time of the carrier of the shutting down capacity cell **602** into parts to be borrowed by different co-paired coverage cells (**604A-604B**). The splitting may be based on one or more of KPIs of the co-paired coverage cells (**604A-604B**), the KPIs including a load experienced by each of the co-paired coverage cells (**604A-604B**), an overlapping region of each of the co-paired coverage cells (**604A-604B**) with the shutting down capacity cell **602** and a latency of each of the co-paired coverage cells (**604A-604B**).

FIGS. 7A-7B are flow diagrams that illustrate a method of controlling carrier shutdowns in a multi-carrier cellular network in accordance with an implementation of the disclosure. At a step **702**, an information about Active Antenna Unit, AAU, configuration of one or more capacity cells paired with a coverage cell in the multi-carrier cellular network is obtained by the coverage cell. At a step **704**, an information about coverage cell load and carrier borrowing capabilities of an AAU of the coverage cell is sent to the paired capacity cells by the coverage cell. At a step **706**, each of the paired capacity cells determines whether a carrier shutdown entry condition of the capacity cell is met with a carrier borrowing by the coverage cell in accordance with the carrier borrowing capabilities is determined by each of the paired capacity cells. At a step **708**, each of the paired capacity cells in which carrier shutdown entry condition is determined to be met with the carrier borrowing is shutting down. At a step **710**, a carrier is borrowed from one of the shutting down paired capacity cells by the coverage

cell with using the AAU configuration of the capacity cell to activate the borrowed carrier, if it is determined by the coverage cell that a carrier borrowing condition is met.

The method increases the shutting down time of the capacity cell by allowing neighboring coverage cell to borrow a carrier frequency of the capacity cell (e.g. in 4G and 5G networks), due to its relation with the paired coverage cell. By allowing the AAU of the coverage cell to borrow the carrier frequency of a shutting down capacity cell, the coverage cell capacity increases, thus enabling it to offload more traffic from the shutting down capacity cell. Then, the capacity cell may shutdown more often and for longer time, and may be re-activated less frequently. The method is semi-static and increases shutting down time of the capacity cell based on load measurement at the coverage cell and the paired capacity cell.

The method is energy efficient as the activation of the borrowed carrier at the AAU of the coverage cell only requires a slight increase in power consumption due to shared hardware between co-deployed carriers in the AAU of the coverage cell. Further, the method requires a limited additional signaling exchange as the coverage cell acquires beforehand the capabilities and configuration of the paired capacity cells in terms of a number of carriers, their frequencies and bandwidths and informs its paired capacity cells about changes in the borrowing capabilities of its AAU.

Optionally, the carrier borrowing condition is met if a load of the coverage cell is above a pre-defined carrier borrowing activation threshold and below a pre-defined carrier shutdown leaving threshold. The carrier borrowing condition may depend on one or more of Key Performance Indicators, KPIs, of the coverage cell and/or the paired capacity cell, including a load, a number of connected User Equipment, UEs, coverage holes, cell rates and cell delays.

Optionally, the method further includes releasing, by the coverage cell, the carrier borrowed from the shutdown paired capacity cell, when it is determined by the coverage cell that a carrier releasing condition is met. The method further includes re-borrowing, by the coverage cell, the carrier from the shutdown paired capacity cell, when it is determined by the coverage cell that the carrier borrowing condition is met.

Optionally, the carrier releasing condition is met if the mean of the coverage cell load at the borrowed carrier and the coverage cell load at its own carrier is below a pre-defined carrier borrowing releasing threshold.

Optionally, the method further includes determining, by the coverage cell, if a carrier shutdown leaving condition for the shutdown paired capacity cell is met. The method further includes sending, by the coverage cell, a cell activation message to activate the shutdown paired capacity cell which carrier shutdown leaving condition is determined as met. The method further includes releasing the carrier borrowed by the coverage cell from the activated paired capacity cell.

Optionally, the carrier shutdown leaving condition is met if the mean of the coverage cell load at the borrowed carrier and the coverage cell load at its own carrier is above a pre-defined carrier shutdown leaving threshold. The carrier shutdown leaving condition may depend on one or more of KPIs of the coverage cell related to the borrowed carrier and/or its own carrier, including a load, a number of connected User Equipment, UEs, coverage holes, cell rate and cell delay.

Optionally, the method further includes initiating an inter-frequency handover by the coverage cell to transfer any user equipment, UEs, connected to the coverage cell at the borrowed carrier to the own carrier of the coverage cell before sending the cell activation message to the shutdown paired capacity cell. The sending of the cell activation message to activate the shutdown paired capacity cell includes (i) sending an AAU activation message by the coverage cell as the cell activation message to a Base Band Unit, BBU, of the shutdown paired capacity cell, (ii) activating the AAU of the shutdown paired capacity cell by the BBU, and (iii) conducting a mobility load balancing to balance the load between the own carrier of the coverage cell and the carrier of the capacity cell formerly borrowed by the coverage cell. The releasing of the carrier borrowed by the coverage cell includes releasing the borrowed carrier by the BBU of the coverage cell in response to receiving a confirmation from the BBU of the paired capacity cell that its AAU is activated, and the mobility load balancing is implemented.

Optionally, the method further includes determining, by the coverage cell, that the carrier shutdown leaving condition is met for a part of the borrowed carrier of the shutdown paired capacity cell. The method further includes suspending, by the coverage cell, the borrowed carrier from accepting new UE connections. The sending of the cell activation message to activate the shutdown paired capacity cell includes (i) sending by the coverage cell to a Base Band Unit, BBU, of the shutdown paired capacity cell a partial carrier activation message as the cell activation message, the partial carrier activation message indicating that the part of the capacity cell carrier is to be activated, and (ii) activating the part of the capacity cell carrier at the AAU of the shutdown paired capacity cell by the BBU. The releasing of the carrier borrowed by the coverage cell includes (i) transferring UEs connected to the coverage cell at the borrowed carrier to the activated part of the paired capacity cell carrier, and (ii) releasing the borrowed carrier by the coverage cell when its load is below a pre-defined coverage cell threshold for releasing carrier borrowing with sending a release message to the BBU of the partially activated paired capacity cell.

Optionally, the information about AAU configuration of each capacity cell includes a number of carriers owned by the capacity cell, frequencies and bandwidths of the carriers. The information about carrier borrowing capabilities of an AAU of the coverage cell includes an information about available AAU slots at the AAU and processing resources of a Base Band Unit, BBU, of the AAU of the coverage cell.

Optionally, the method further includes defining a shutdown policy for each capacity cell of the multi-carrier cellular network. The shutdown policy includes a carrier shutdown entry condition and a carrier shutdown leaving condition. The carrier shutdown entry condition is met when a combined load of the capacity cell and the coverage cell is below a carrier shutdown threshold.

Optionally, the carrier shutdown threshold is defined during a pairing process of the coverage cell and the capacity cell as a function of a cell overlapping factor computed in a co-coverage analysis within the pairing process. Optionally, the method further includes initiating by the paired capacity cell an inter-frequency handover to the coverage cell before shutting down the paired capacity cell.

Optionally, the borrowing of the carrier from the shutdown paired capacity cell by the coverage cell includes (i) sending a carrier borrowing message by the coverage cell to a BBU of the shutdown paired capacity cell, (ii) allocating one slot of the AAU of the coverage cell to the borrowed carrier, and (iii) allocating processing resources of the BBU of the coverage cell to the allocated slot of the AAU.

Optionally, one of the capacity cells paired with the coverage cell is paired with one or more additional coverage cells and the method further includes coordinating the coverage cell with the additional coverage cells to enable only one of the co-paired coverage cells borrowing a carrier from the shutting down capacity cell.

Optionally, the coordinating of the coverage cell with the additional coverage cells includes enabling the one of the co-paired coverage cells that experiences a larger load and/or has a largest overlapping region with the shutting down capacity cell to borrow a carrier from the shutting down capacity cell.

Optionally, one of the capacity cells paired with the coverage cell is paired with one or more additional coverage cells and the method further includes enabling only one of the co-paired coverage cells to borrow a carrier from the shutting down capacity cell by the BBU of the shutting down capacity cell based on loads and/or other KPIs of the co-paired coverage cells.

Optionally, one of the capacity cells paired with the coverage cell is paired with one or more additional coverage cells and the method further includes splitting, by the BBU of the shutting down capacity cell, an available bandwidth in time of the carrier of the shutting down capacity cell into parts to be borrowed by different co-paired coverage cells. The splitting may be based on one or more of KPIs of the co-paired coverage cells, the KPIs including a load experienced by each of the co-paired coverage cells, an overlapping region of each of the co-paired coverage cells with the shutting down capacity cell, and a latency of each of the co-paired coverage cells.

It should be understood that the arrangement of components illustrated in the figures described are exemplary and that other arrangement may be possible. It should also be understood that the various system components (and means) defined by the claims,

described below, and illustrated in the various block diagrams represent components in some systems configured according to the subject matter disclosed herein. For example, one or more of these system components (and means) may be realized, in whole or in part, by at least some of the components illustrated in the arrangements illustrated in the described figures.

In addition, while at least one of these components are implemented at least partially as an electronic hardware component, and therefore constitutes a machine, the other components may be implemented in software that when included in an execution environment constitutes a machine, hardware, or a combination of software and hardware.

Although the disclosure and its advantages have been described in detail, it should be understood that various changes, substitutions, and alterations can be made herein without departing from the spirit and scope of the disclosure as defined by the appended claims.

CLAIMS

1. A method of controlling carrier shutdowns in a multi-carrier cellular network, comprising:

obtaining, by a coverage cell (204, 404, 504, 604A-B) in the multi-carrier cellular network, an information about Active Antenna Unit, AAU, configuration of one or more capacity cells (202, 402, 502, 602) paired with the coverage cell,

sending, by the coverage cell, an information about coverage cell load and carrier borrowing capabilities of an AAU of the coverage cell to the paired capacity cells,

determining, by each of the paired capacity cells, if a carrier shutdown entry condition of said capacity cell is met with a carrier borrowing by the coverage cell in accordance with the carrier borrowing capabilities,

shutting down each of the paired capacity cells which carrier shutdown entry condition is determined to be met with the carrier borrowing, and

borrowing a carrier from one of the shutting down paired capacity cells by the coverage cell with using the AAU configuration of said capacity cell to activate the borrowed carrier, if it is determined by the coverage cell that a carrier borrowing condition is met.

2. The method of claim 1, wherein the carrier borrowing condition is met if a load of the coverage cell is above a pre-defined carrier borrowing activation threshold and below a pre-defined carrier shutdown leaving threshold.

3. The method of claim 1, wherein the carrier borrowing condition depends on one or more of Key Performance Indicators, KPIs, of the coverage cell and/or the paired capacity cell, comprising a load, a number of connected User Equipment, UEs, coverage holes, cell rates and cell delays.

4. The method of any of claims 1 to 3, further comprising:

releasing, by the coverage cell, the carrier borrowed from the shutdown paired capacity cell, when it is determined by the coverage cell that a carrier releasing condition is met, and

re-borrowing, by the coverage cell, the carrier from the shutdown paired capacity cell, when it is determined by the coverage cell that the carrier borrowing condition is met.

5. The method of claim 4, wherein the carrier releasing condition is met if the mean of the coverage cell load at the borrowed carrier and the coverage cell load at its own carrier is below a pre-defined carrier borrowing releasing threshold.

6. The method of any of claims 1 to 5, further comprising:

determining, by the coverage cell, if a carrier shutdown leaving condition for the shutdown paired capacity cell is met,

sending, by the coverage cell, a cell activation message to activate the shutdown paired capacity cell which carrier shutdown leaving condition is determined as met, and

releasing the carrier borrowed by the coverage cell from the activated paired capacity cell.

7. The method of claim 6, wherein the carrier shutdown leaving condition is met if the mean of the coverage cell load at the borrowed carrier and the coverage cell load at its own carrier is above a pre-defined carrier shutdown leaving threshold.

8. The method of 6, wherein the carrier shutdown leaving condition depends on one or more of KPIs of the coverage cell related to the borrowed carrier and/or its own carrier, comprising a load, a number of connected User Equipment, UEs, coverage holes, cell rate and cell delay.

9. The method of any of claims 6 to 8, further comprising:

initiating an inter-frequency handover by the coverage cell to transfer any user equipment, UEs, connected to the coverage cell at the borrowed carrier to the own

carrier of the coverage cell before sending the cell activation message to the shutdown paired capacity cell,

wherein the sending of the cell activation message to activate the shutdown paired capacity cell comprises:

sending an AAU activation message by the coverage cell as the cell activation message to a Base Band Unit, BBU, of the shutdown paired capacity cell,

activating the AAU of the shutdown paired capacity cell by the BBU, and

conducting a mobility load balancing to balance the load between the own carrier of the coverage cell and the carrier borrowed by the coverage cell,

wherein the releasing of the carrier borrowed by the coverage cell comprises releasing the borrowed carrier by the BBU of the coverage cell in response to receiving a confirmation from the BBU of the paired capacity cell that its AAU is activated, and the mobility load balancing is implemented.

10. The method of any of claims 6 to 8, further comprising:

determining, by the coverage cell, that the carrier shutdown leaving condition is met for a part of the borrowed carrier of the shutdown paired capacity cell, and

suspending, by the coverage cell, the borrowed carrier from accepting new UE connections,

wherein the sending of the cell activation message to activate the shutdown paired capacity cell comprises:

sending by the coverage cell to a Base Band Unit, BBU, of the shutdown paired capacity cell a partial carrier activation message as the cell activation message, the partial carrier activation message indicating that the part of the capacity cell carrier is to be activated, and

activating the part of the capacity cell carrier at the AAU of the shutdown paired capacity cell by the BBU,

wherein the releasing of the carrier borrowed by the coverage cell comprises:

transferring UEs connected to the coverage cell at the borrowed carrier to the activated part of the paired capacity cell carrier, and

releasing the borrowed carrier by the coverage cell when its load is below a pre-defined coverage cell threshold for releasing carrier borrowing with sending a release message to the BBU of the partially activated paired capacity cell.

11. The method of any of claims 1 to 10, wherein the information about AAU configuration of each capacity cell comprises a number of carriers owned by the capacity cell, frequencies and bandwidths of said carriers, and the information about carrier borrowing capabilities of an AAU of the coverage cell comprises an information about available AAU slots at the AAU and processing resources of a Base Band Unit, BBU, of the AAU of the coverage cell.

12. The method of any of claims 1 to 10, further comprising:

defining a shutdown policy for each capacity cell of the multi-carrier cellular network, the shutdown policy comprises a carrier shutdown entry condition and a carrier shutdown leaving condition, wherein the carrier shutdown entry condition is met when a combined load of the capacity cell and the coverage cell is below a carrier shutdown threshold.

13. The method of claim 13, wherein the carrier shutdown threshold is defined during a pairing process of the coverage cell and the capacity cell as a function of a cell overlapping factor computed in a co-coverage analysis within the pairing process.

14. The method of any of claims 1 to 13, wherein the method further comprises initiating by the paired capacity cell an inter-frequency handover to the coverage cell before shutting down the paired capacity cell.

15. The method of any of claims 1 to 14, wherein the borrowing of the carrier from the shutdown paired capacity cell by the coverage cell comprises:

sending a carrier borrowing message by the coverage cell to a BBU of the shutdown paired capacity cell,

allocating one slot of the AAU of the coverage cell to the borrowed carrier, and

allocating processing resources of the BBU of the coverage cell to said allocated slot of the AAU.

16. The method of any of claims 1 to 15, wherein one of the capacity cells (202, 402, 502, 602) paired with the coverage cell (604A) is paired with one or more additional coverage cells (604B) and the method further comprises:

coordinating the coverage cell (604A) with the additional coverage cells (604B) to enable only one of the co-paired coverage cells (604A-B) borrowing a carrier from the shutting down capacity cell.

17. The method of claim 16, wherein the coordinating of the coverage cell with the additional coverage cells comprises enabling the one of the co-paired coverage cells that experiences a larger load and/or has a largest overlapping region with the shutting down capacity cell to borrow a carrier from the shutting down capacity cell.

18. The method of any of claims 1 to 15, wherein one of the capacity cells paired with the coverage cell is paired with one or more additional coverage cells and the method further comprises:

enabling only one of the co-paired coverage cells to borrow a carrier from the shutting down capacity cell by the BBU of the shutting down capacity cell based on loads and/or other KPIs of the co-paired coverage cells.

19. The method of any of claims 1 to 15, wherein one of the capacity cells paired with the coverage cell is paired with one or more additional coverage cells and the method further comprises:

splitting, by the BBU of the shutting down capacity cell, an available bandwidth in time of the carrier of the shutting down capacity cell into parts to be borrowed by different co-paired coverage cells.

20. The method of claim 16, wherein the splitting is based on one or more of KPIs of the co-paired coverage cells, the KPIs comprising a load experienced by each of the co-paired coverage cells, an overlapping region of each of the co-paired coverage cells with the shutting down capacity cell and a latency of each of the co-paired coverage cells.

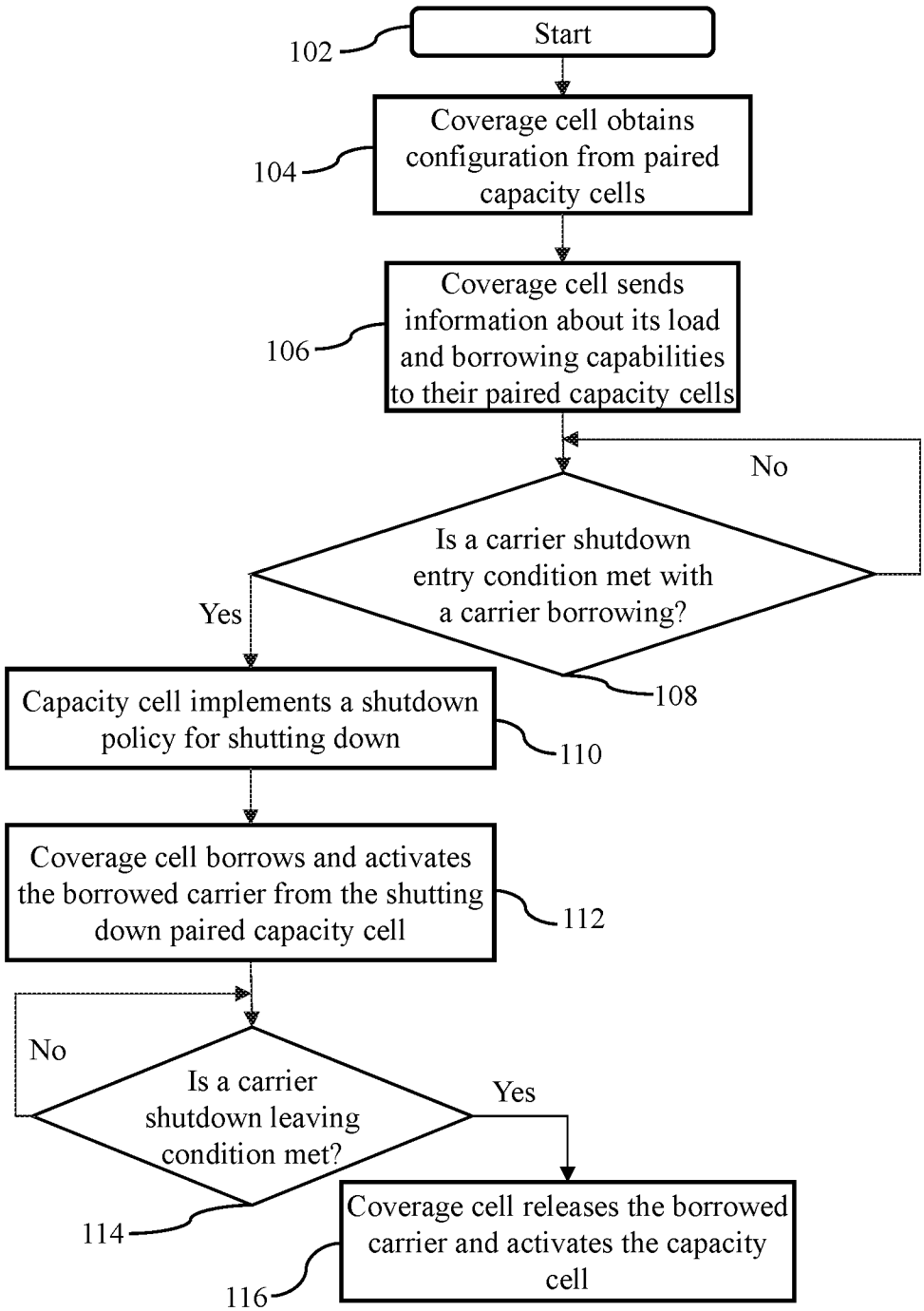
Start
102
Coverage cell obtains configuration from paired capacity cells
104
Coverage cell sends information about its load and borrowing capabilities to their paired capacity cells
106
No
Is a carrier shutdown entry condition met with a carrier borrowing?
108
Yes
Capacity cell implements a shutdown policy for shutting down
110
Coverage cell borrows and activates the borrowed carrier from the shutting down paired capacity cell
112
No
Is a carrier shutdown leaving condition met?
114
Yes
Coverage cell releases the borrowed carrier and activates the capacity cell
116

FIG. 1

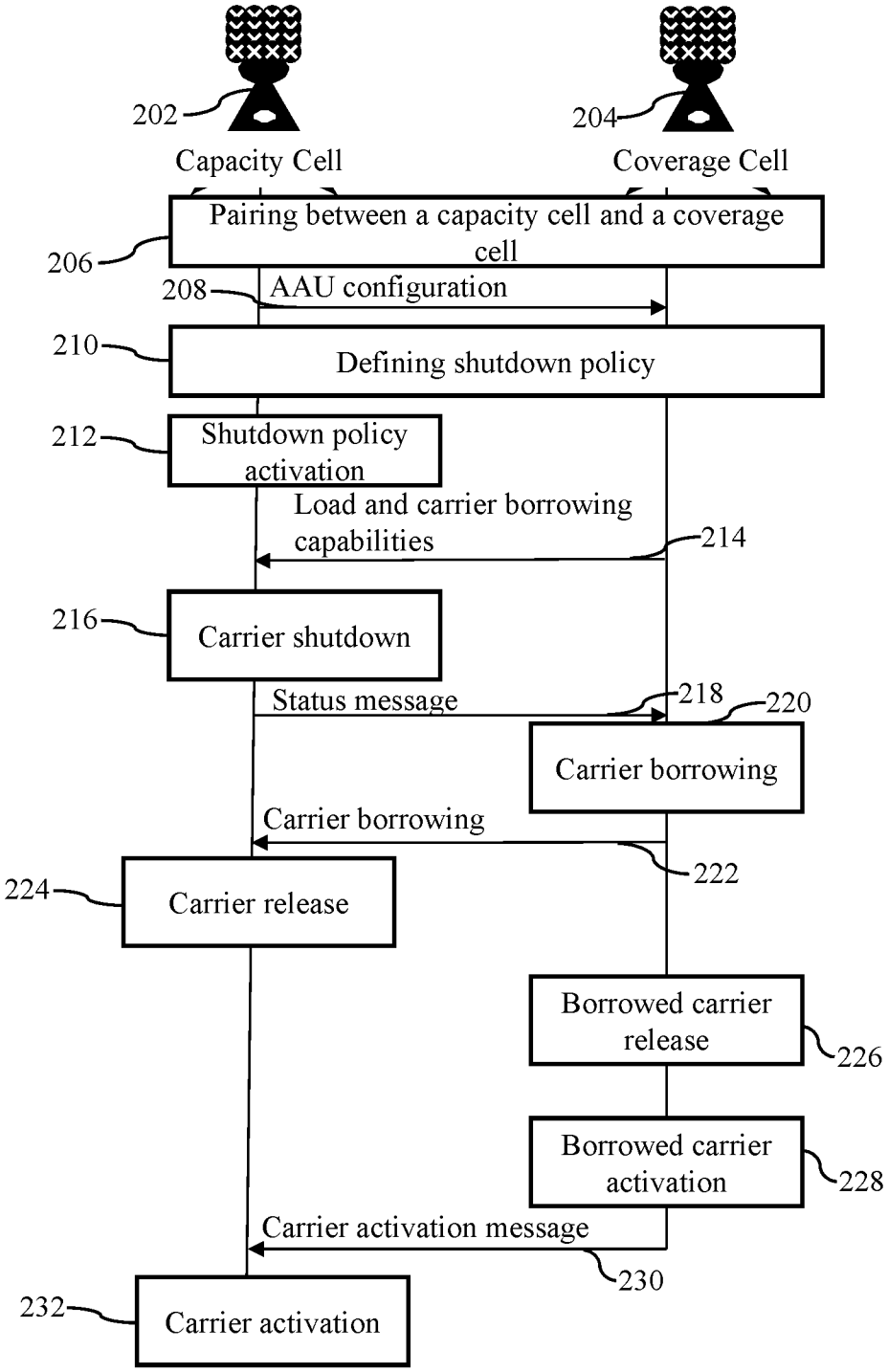
202
204
Capacity Cell
Coverage Cell
Pairing between a capacity cell and a coverage cell
206
208
AAU configuration
210
Defining shutdown policy
212
Shutdown policy activation
Load and carrier borrowing capabilities
214
216
Carrier shutdown
Status message
218
220
Carrier borrowing
Carrier borrowing
222
224
Carrier release
Borrowed carrier release
226
Borrowed carrier activation
228
Carrier activation message
230
232
Carrier activation

FIG. 2

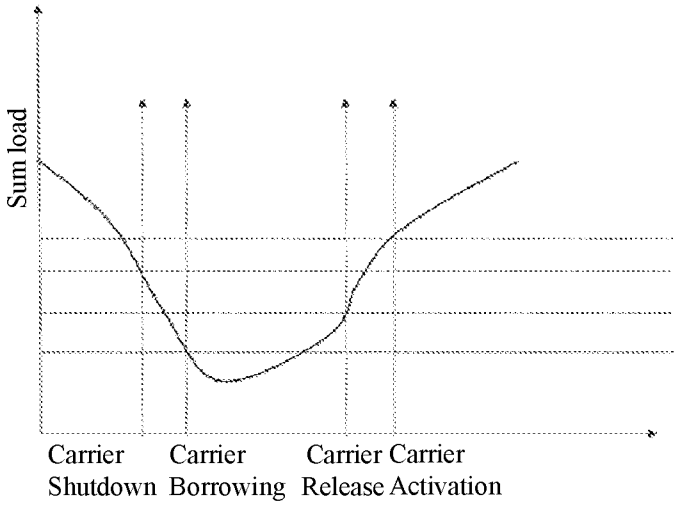
Sum load
Carrier Shutdown
Carrier Borrowing
Carrier Release
Carrier Activation

FIG. 3

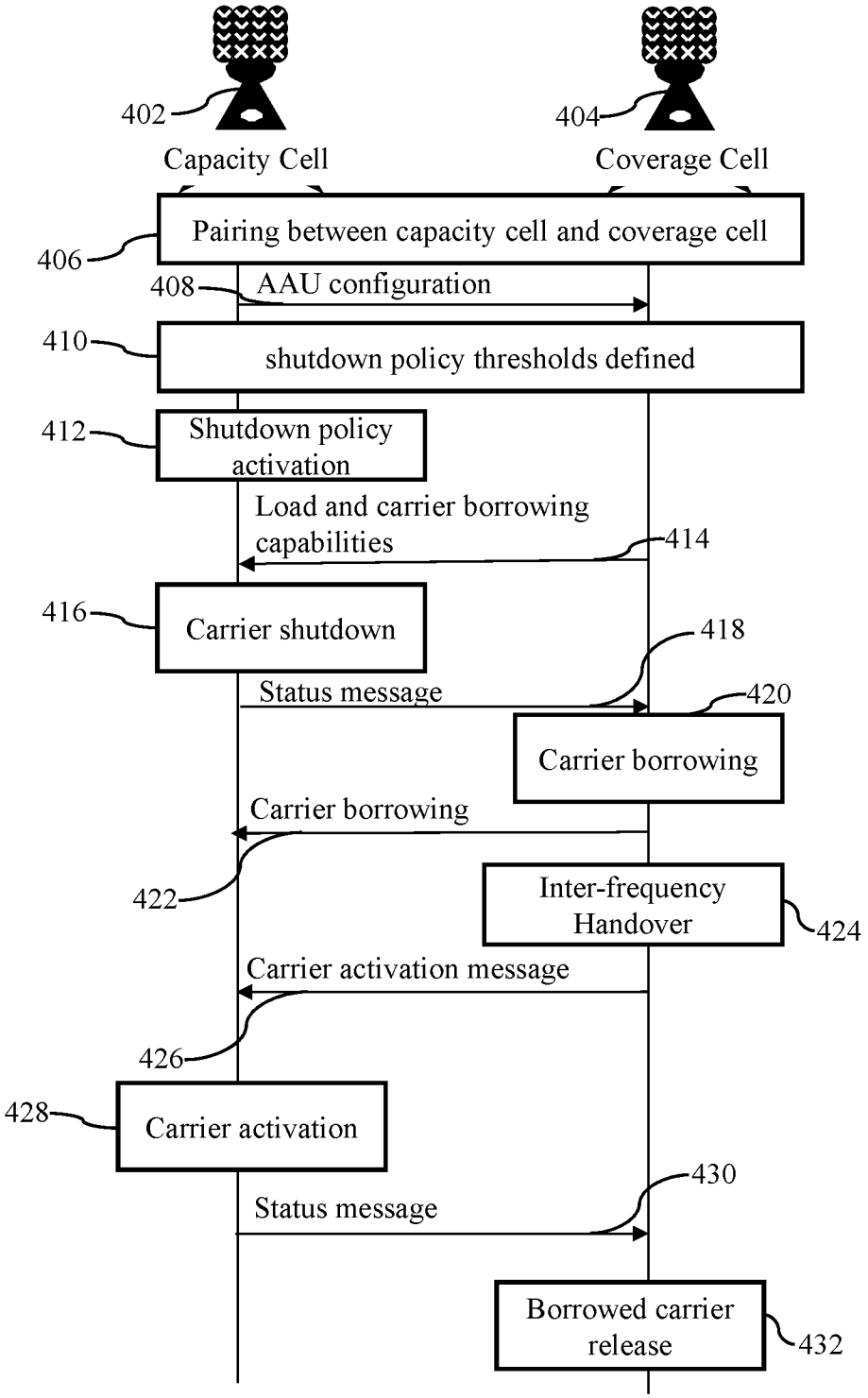
402
Capacity Cell
404
Coverage Cell
Pairing between capacity cell and coverage cell
406
408
AAU configuration
410
shutdown policy thresholds defined
412
Shutdown policy activation
Load and carrier borrowing capabilities
414
416
Carrier shutdown
418
Status message
420
Carrier borrowing
Carrier borrowing
422
Inter-frequency Handover
424
Carrier activation message
426
428
Carrier activation
430
Status message
Borrowed carrier release
432

FIG. 4

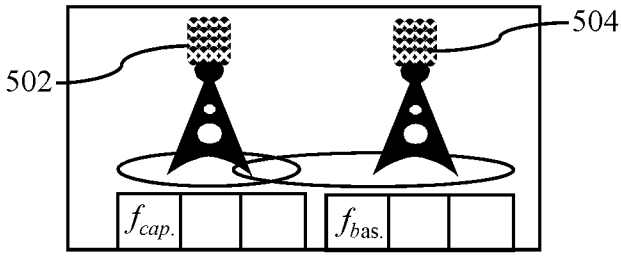

FIG. 5A

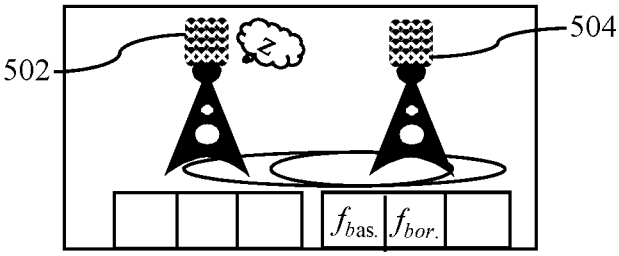

FIG. 5B

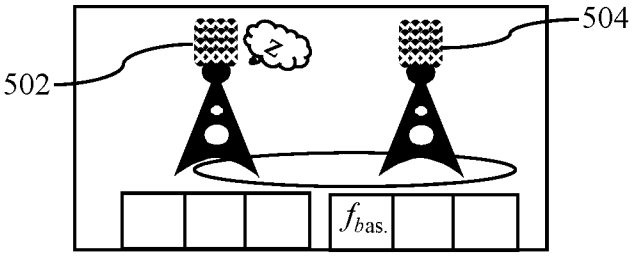

FIG. 5C

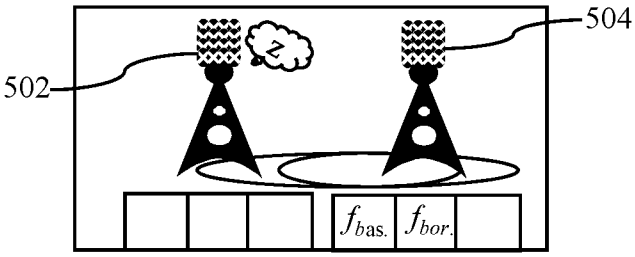

FIG. 5D

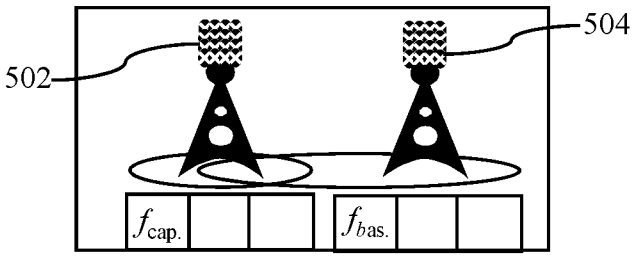

FIG. 5E

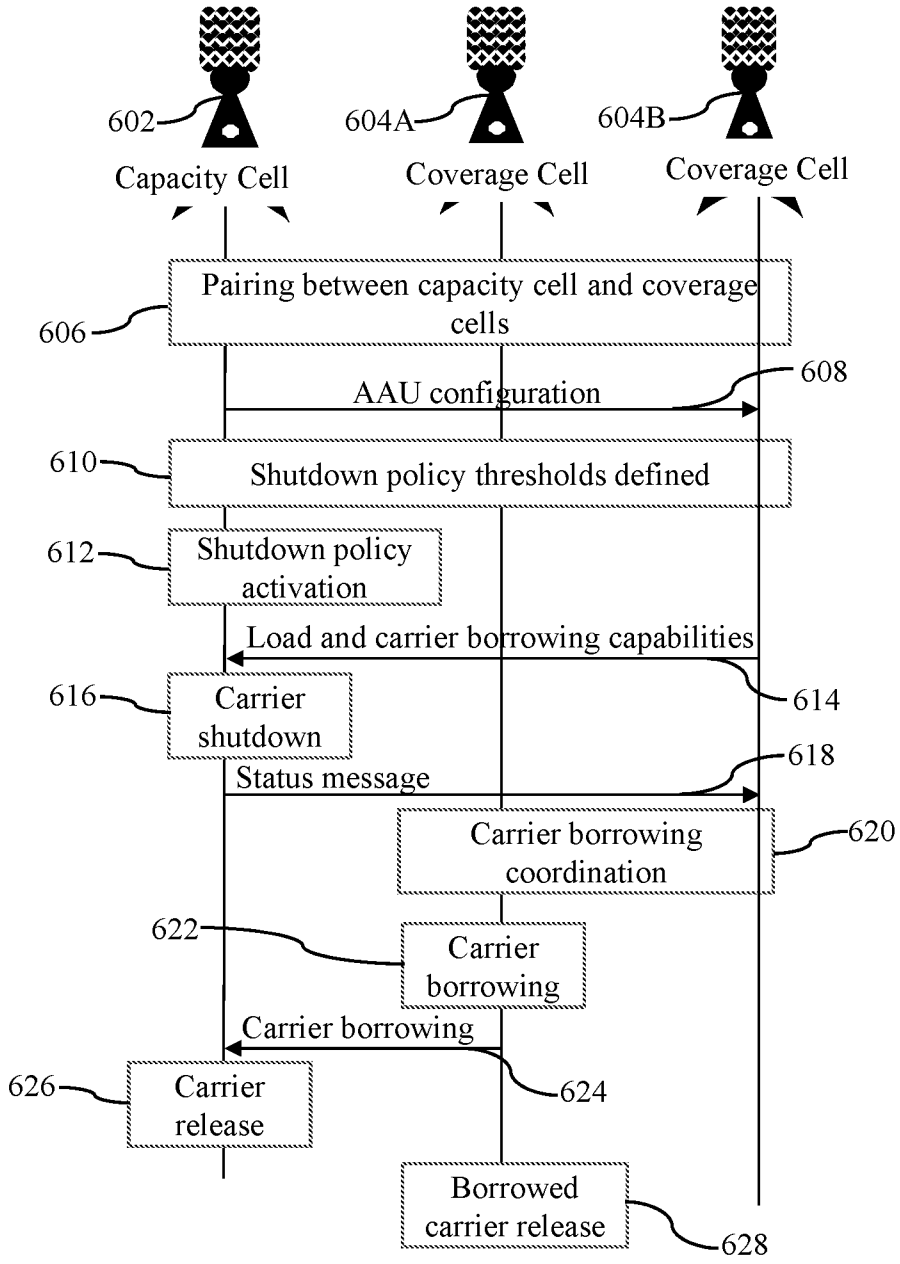
602
604A
604B
Capacity Cell
Coverage Cell
Coverage Cell
Pairing between capacity cell and coverage cells
606
AAU configuration
608
610
Shutdown policy thresholds defined
612
Shutdown policy activation
Load and carrier borrowing capabilities
614
616
Carrier shutdown
618
Status message
Carrier borrowing coordination
620
622
Carrier borrowing
Carrier borrowing
624
626
Carrier release
Borrowed carrier release
628

FIG. 6

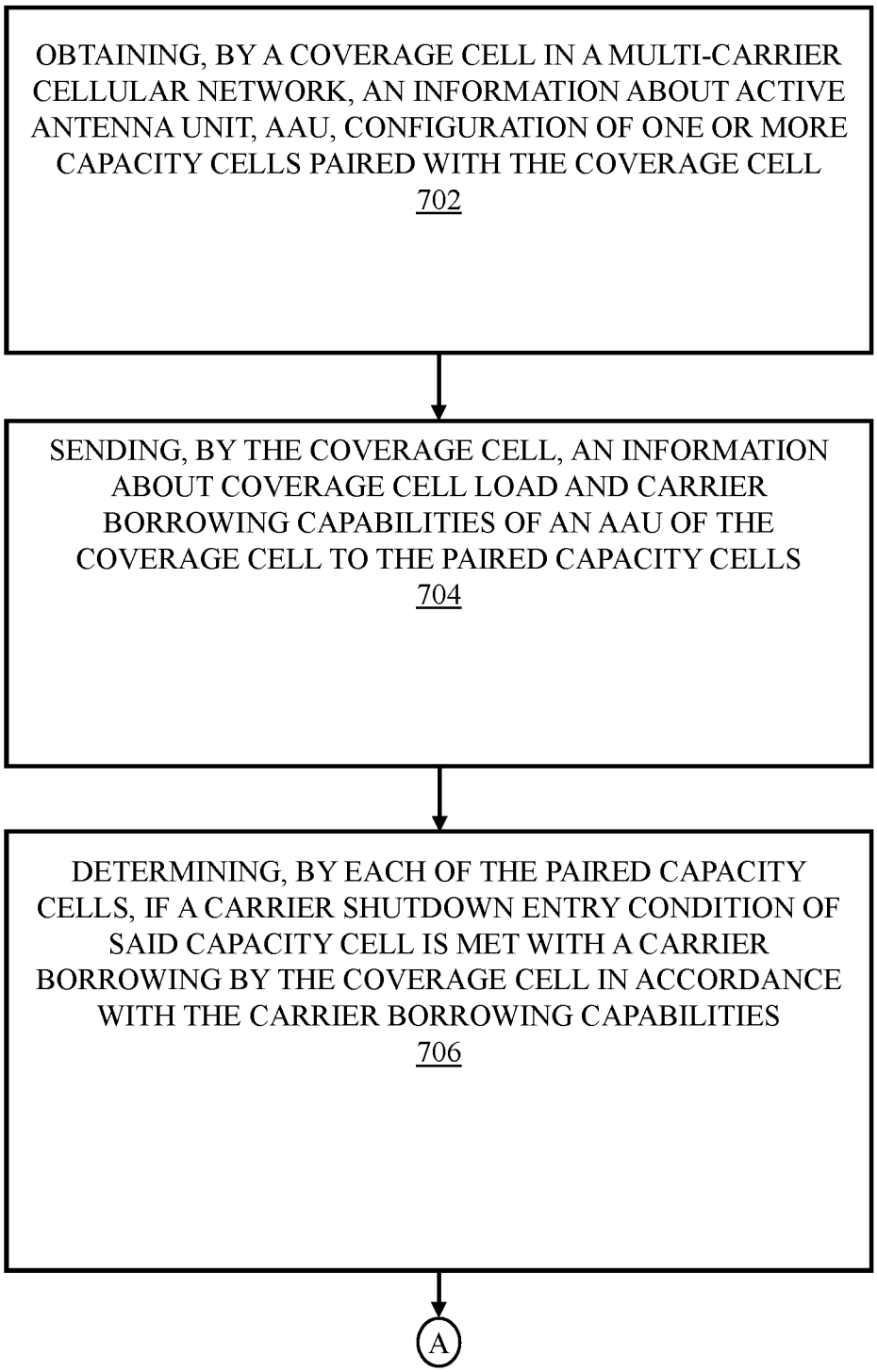
OBTAINING, BY A COVERAGE CELL IN A MULTI-CARRIER CELLULAR NETWORK, AN INFORMATION ABOUT ACTIVE ANTENNA UNIT, AAU, CONFIGURATION OF ONE OR MORE CAPACITY CELLS PAIRED WITH THE COVERAGE CELL
702
SENDING, BY THE COVERAGE CELL, AN INFORMATION ABOUT COVERAGE CELL LOAD AND CARRIER BORROWING CAPABILITIES OF AN AAU OF THE COVERAGE CELL TO THE PAIRED CAPACITY CELLS
704
DETERMINING, BY EACH OF THE PAIRED CAPACITY CELLS, IF A CARRIER SHUTDOWN ENTRY CONDITION OF SAID CAPACITY CELL IS MET WITH A CARRIER BORROWING BY THE COVERAGE CELL IN ACCORDANCE WITH THE CARRIER BORROWING CAPABILITIES
706
A

FIG. 7A

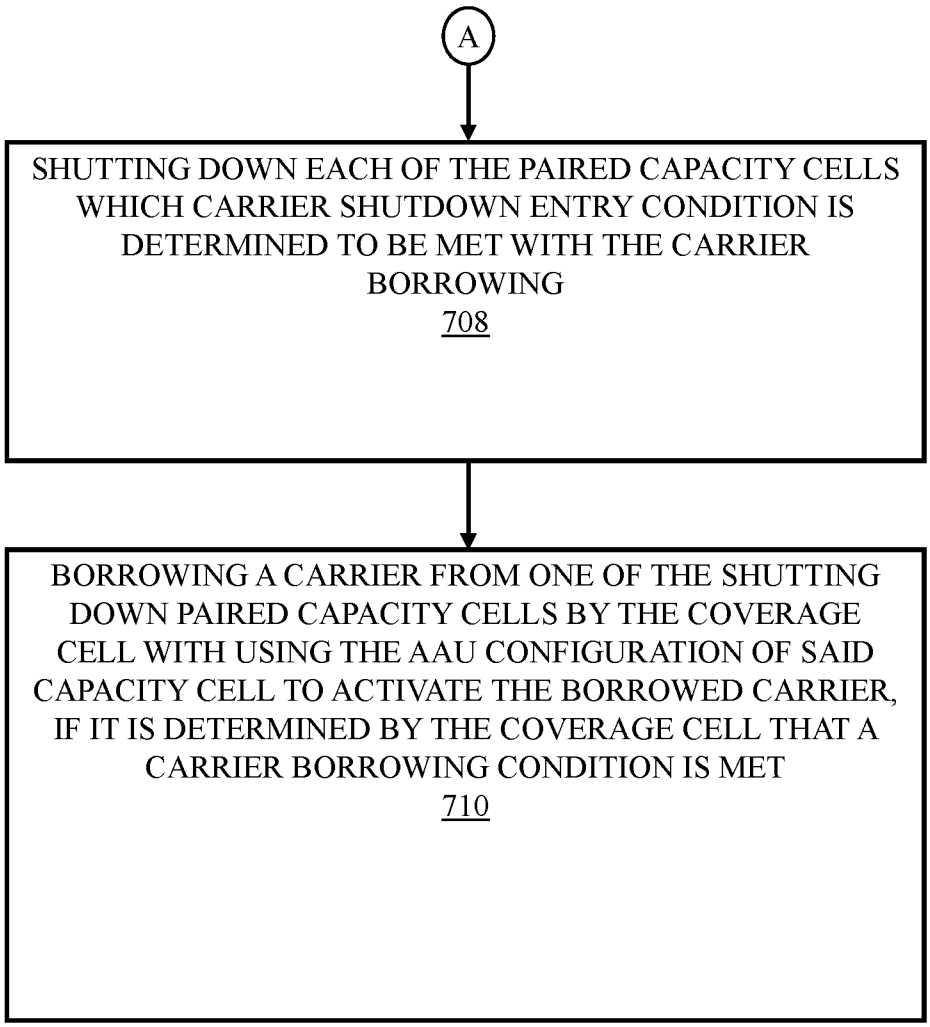
A
SHUTTING DOWN EACH OF THE PAIRED CAPACITY CELLS WHICH CARRIER SHUTDOWN ENTRY CONDITION IS DETERMINED TO BE MET WITH THE CARRIER BORROWING
708
BORROWING A CARRIER FROM ONE OF THE SHUTTING DOWN PAIRED CAPACITY CELLS BY THE COVERAGE CELL WITH USING THE AAU CONFIGURATION OF SAID CAPACITY CELL TO ACTIVATE THE BORROWED CARRIER, IF IT IS DETERMINED BY THE COVERAGE CELL THAT A CARRIER BORROWING CONDITION IS MET
710

FIG. 7B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2022/139002

A. CLASSIFICATION OF SUBJECT MATTER

H04L 27/00(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)

IPC: 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)

CNTXT,ENTXTC,DWPI,VEN,3GPP: carrier, shutdown?, multi-carrier, capacity, cell+, coverage, Active, Antenna, Unit, AAU, paired, borrow+, capabilit+, shut+, clos+, energy, saving, power, high, band, low

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	CN 112996060 A (CHINA MOBILE GROUP ZHEJIANG COMPANY LIMITED et al.) 18 June 2021 (2021-06-18) description,paragraphs 5-52	1-20
A	CN 114077213 A (DATANG MOBILE COMMUNICATIONS EQUIPMENT CO., LTD.) 22 February 2022 (2022-02-22) the whole document	1-20
A	WO 2022179339 A1 (HUAWEI TECHNOLOGIES CO., LTD.) 01 September 2022 (2022-09-01) the whole document	1-20
A	CMCC. "AI based Energy Saving" *3GPP TSG-RAN WG3 Meeting #112 electronic R3-212507,* 28 May 2021 (2021-05-28), the whole document	1-20

☐ 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
"D" document cited by the applicant in the international application
"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
10 August 2023	**17 August 2023**

Name and mailing address of the ISA/CN	Authorized officer
CHINA NATIONAL INTELLECTUAL PROPERTY ADMINISTRATION **6, Xitucheng Rd., Jimen Bridge, Haidian District, Beijing 100088, China**	**FEI,YuHui** Telephone No. **(+86) 010-53961778**

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2022/139002

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
CN 112996060 A	18 June 2021	None	
CN 114077213 A	22 February 2022	None	
WO 2022179339 A1	01 September 2022	CN 114980282 A	30 August 2022