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(54) Title: MULTI-CONNECTIVITY SUPPORT AND FAST CELL SWITCHING FOR MMWAVE CELLULAR RADIO ACCESS TECHNOLOGIES

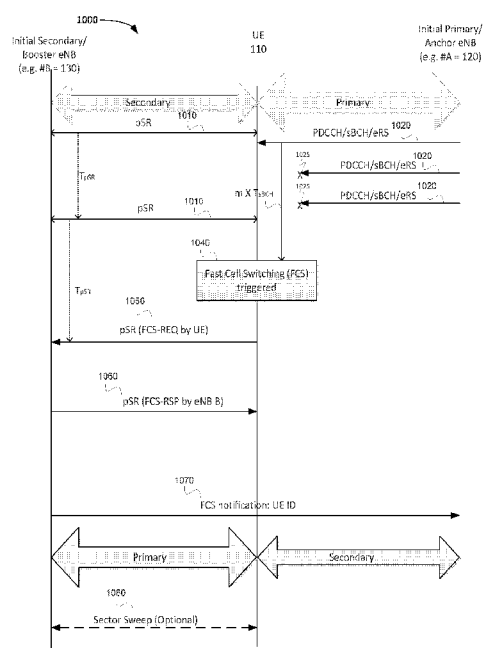


Fig. 10

(57) Abstract: Embodiments relate to a User Equipment (UE) to communicate with an Evolved Node B (eNB) on a wireless network, comprising one or more processors to connect/communicate with at least a first anchor eNB and a second booster eNB, maintain a plurality of radio access network communications links between the UE and a radio access network of the wireless network, said plurality of radio access network communications links between the UE and a radio access network of the wireless network comprising at least one primary and at least one secondary communications link, switch between actively using the at least one primary communications link for sending and receiving data of the UE to actively using the at least one secondary communications link for sending and receiving data of the UE when the at least one primary communications link is determined to be lost. Other embodiments may be described/claimed.

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MULTI-CONNECTIVITY SUPPORT AND FAST CELL SWITCHING FOR MMWAVE CELLULAR RADIO ACCESS TECHNOLOGIES

TECHNICAL FIELD

5 Embodiments described herein generally relate to the field of wireless communications systems.

BACKGROUND

 Various wireless cellular communication systems have been implemented or are being proposed, including a 3rd Generation Partnership Project (3GPP) Universal Mobile
10 Telecommunications System (UMTS), a 3GPP Long-Term Evolution (LTE) system, a 3GPP LTE-Advanced system, and a 5th Generation wireless system / 5th Generation mobile networks (5G) system / 5th Generation new radio (NR) system.

 Some proposed cellular communication systems may incorporate radio frequencies including one or more frequency bands between 30 gigahertz and 300 gigahertz.
15 Corresponding with radio wavelengths from 10 mm to 1 mm, such communication systems may sometimes be referred to as millimeter wave (mmWave) systems.

BRIEF DESCRIPTION OF THE DRAWINGS

 The embodiments of the disclosure will be understood more fully from the detailed description given below and from the accompanying drawings of various embodiments of the
20 disclosure. However, while the drawings are to aid in explanation and understanding, they are only an aid, and should not be taken to limit the disclosure to the specific embodiments depicted therein.

 Figure 1 shows a proposed multi-connectivity network architecture according to examples;

25 Figure 2 shows an example of a possible end to end (e2e) user-plane protocol stack for the proposed multi-connectivity network architecture of Figure 1;

 Figure 3 shows an example of a possible end to end (e2e) control-plane protocol stack for the proposed multi-connectivity network architecture of Figure 1;

30 Figure 4 shows a first optional example of how PSS/SSS/SLS synchronization signals from neighboring cells may be distributed in a frame;

 Figure 5 shows a second optional example of how PSS/SSS/SLS synchronization signals from neighboring cells may be distributed in a frame;

Figure 6 shows how a short broadcast (sBCH) according to examples may be allocated in a subframe with three sectors: A, B, and C;

Figure 7 shows how a persistent Scheduling Request request message (pSR-REQ) and a persistent Scheduling Request response message (pSR-RSP) may be allocated in a special
5 subframe, around the existing content;

Figure 8 shows how the pSR-REQ and pSR-RSP messages may be allocated in a normal subframe, around the existing content;

Figure 9 shows a high level flow diagram of a method of detecting communications link loss according to an example;

10 Figure 10 shows a portion of a method for a UE to detect the loss of a primary communications link and the resultant switch of its primary cell, according to some examples;

Figure 11 illustrates hardware processing circuitries for a UE and eNB, in accordance with some examples;

15 Figure 12 shows an example implementation of an electronic device (e.g. UE or eNB) in accordance with some examples;

Figure 13 shows a diagrammatic representation of hardware resources in accordance with some examples.

DETAILED DESCRIPTION

20 Millimeter wave (mmWave) systems have a potential to provide enormous bandwidth. mmWave systems may also be called high frequency band systems, or extremely high frequency band systems. Due to the potential bandwidth, mmWave systems are a candidate for supporting future 5G systems. In some cases, mmWave small cells may be deployed in an LTE-assisted “anchor booster” mode. In other cases, mmWave small cells
25 may be deployed to operate in a standalone manner (e.g., without assistance from an LTE macro cell). A cell is a logical concept, and may be referenced as a Radio Access Network (or part thereof). A cell may be provided by a single evolved Node-B (eNB) and Radio head end, or multiple radio head ends of an eNB, dependent on the particular cell provision architecture. This is to say, an eNB is a physical equipment, and an eNB may operate one, or
30 multiple cells.

High frequency band systems such as mmWave systems may require directional beamforming on the part of both an Evolved Node-B (eNB) (or Access Point (AP)/Base

Station (BS)) and a User Equipment (UE) (or Station (STA)) in order to achieve a Signal-to-Noise Ratio (SNR) conducive to establishing a communication link at the frequencies used. Accordingly, an initial acquisition procedure or access procedure may be used to allow an eNB and a UE to determine the best transmission (TX) and/or receiving (RX) beamforming directions (or beams) for establishing directional connections. Since a mmWave communications link is highly directional and sensitive to the environment, it can therefore be easily blocked (where blocked includes any way in which a communication link between a UE and eNB may be broken or lost – i.e. including where the UE is no longer able to communicate with a eNB (or vice versa) at all, or simply not at a level with sufficient pre-determined performance). Thus examples include total blockages, as well as deemed blockages where communication performance falls below an acceptable (i.e. pre-determined) performance level. In order to reduce the detrimental impact of a lost communications link between a UE and eNB making use of mmWave frequencies for communications therebetween. According to examples, a fast cell switching procedure may be provided to temporarily transition to an alternative (i.e. secondary) mmWave communications link, which serves as a “hot standby” to the main (i.e. primary) mmWave communications link that can be used to minimize service disruption due to blockages. In some examples, the primary or secondary communications links may be Radio Access Technology (RAT) other than a mmWave RAT.

The described fast cell switching procedure(s) may therefore be advantageous in designing an mmWave system or other high frequency band system that is more resilient. The described fast cell switching procedure(s) may utilise a dual-connectivity (DC) procedure to use the (more robust) LTE communications link as the anchor, and the 5G mmWave communications link as the booster. This is to say, the “hot standby” alternative communications link may be another mmWave communications link, or a completely different radio access technology type communications link. In the dual-connectivity (DC) procedure, the UE may maintain both communications links such that whenever the 5G mmWave communications link is temporarily lost, the UE’s data traffic can be seamlessly moved to the LTE communications link.

Moreover, the described fast cell switching procedure(s) may also utilise multiple communications links (e.g. >2) simultaneously, in which situation it may be called a multi-connectivity (MC) procedure, to allow for fast switching among the multiple communications

links. According to examples, mmWave cells may be similar in terms of coverage and reliability (to each other).

The described examples may provide procedures and techniques that are advantageous for both the case of stand-alone deployments (i.e. a single anchor, with effectively only a primary communications link) as well as dual/multi-connectivity deployments (for example where an anchor-booster arrangement is used, with effectively both primary and secondary communications links, and potentially multiple of one or each). In each case, advantages include the maximisation of the use of the mmWave Radio Access Technology (RAT)/cells.

According to examples, while dual connectivity based principles may be used to allow for secondary cells to serve as standby communications links, examples may also provide further optimizations within the radio network to address issues arising from the directional access nature of mmWave based RATs.

According to examples, optimizations provided may support dual/multi-connectivity for mmWave based radio networks, which may include extensions to the dual connectivity architecture.

Specifically, according to examples, there are proposed the following fundamental building blocks to enable high-performance and high-efficiency multi-connectivity and support fast cell switching for mmWave based RATs, and between mmWave cells in particular (both between different mmWave cells, and between mmWave cells and other 5G/LTE, i.e. non mmWave, RAT cells). One of the key issues addressed by examples described herein is the problem of how to switch to alternative communications links at a UE if/once the UE's (original) primary serving cell is blocked, resulting in both the respective control and data links being lost and particularly how to switch to alternative communications links efficiently.

Accordingly, examples provide a new multi-connectivity network architecture which is based on dual connectivity principles but extends this to multi-connectivity by including some key changes that address switching of both the control plane and user plane traffic to a secondary cell/eNB, when the primary mmWave communications link is blocked. According to some examples, the secondary cell(s)/eNB(s) advantageously serve(s) in a "hot standby" mode (i.e. in a mode where they can be utilised immediately).

Examples also provide a new method to coordinate DownLink (DL) synchronization and/or broadcast channel(s) and/or Sector Level Sweep (SLS) among neighboring cells. In

some examples, this may advantageously provide a loose (i.e. only operational at symbol-level time frames) time synchronization.

Examples also provide any one or more of: a new DL broadcast channel, a new DL control channel, or a DL reference signal. Any one or more of these may be advantageously
5 used as a fast communications link loss detection mechanism.

Examples also provide a new method to maintain a low overhead control link with any secondary cells/eNBs put into use that advantageously allows for fast switching when the control link with the primary cell is lost (noting that, typically, if the control link is lost, whether data link is still connected does not matter much, because a UE will lose the
10 connection anyway). The term 'low-overhead' may be considered to mean any system that uses a minimised (or near minimised) level of wireless resources available in respective the Radio Access Network (RAN) or RAT.

Examples also provide a UE-based fast cell switching procedure.

Throughout this disclosure, current LTE terminology for the entities involved are used
15 (e.g. UE, eNB, etc.). This is done mainly to identify a node from 4G/LTE which may share similar logical/conceptual functionalities in 5G, however, it will be appreciated that the actual (accurate) name for those nodes in a 5G system has not been finalized in 3GPP standards yet, and so the present disclosure is not limited in any way to the specific terms used.

In the following description, numerous details are discussed to provide a more thorough
20 explanation of embodiments of the present disclosure. It will be apparent to one skilled in the art, however, that embodiments of the present disclosure may be practiced without these specific details. In other instances, well-known structures and devices are shown in block diagram form, rather than in detail, in order to avoid obscuring embodiments of the present disclosure.

25 Note that in the corresponding drawings of the embodiments, signals are represented with lines. Some lines may be thicker, to indicate a greater number of constituent signal paths, and/or have arrows at one or more ends, to indicate a direction of information flow. Such indications are not intended to be limiting. Rather, the lines are used in connection with one or more exemplary embodiments to facilitate easier understanding of a circuit or a logical
30 unit. Any represented signal, as dictated by design needs or preferences, may actually comprise one or more signals that may travel in either direction and may be implemented with any suitable type of signal scheme.

Throughout the specification, and in the claims, the term "connected" means a direct electrical, mechanical, or magnetic connection between the things that are connected, without any intermediary devices. The term "coupled" means either a direct electrical, mechanical, or magnetic connection between the things that are connected or an indirect connection through one or more passive or active intermediary devices. The term "circuit" or "module" may refer to one or more passive and/or active components that are arranged to cooperate with one another to provide a desired function. The term "signal" may refer to at least one current signal, voltage signal, magnetic signal, or data/clock signal. The meaning of "a," "an," and "the" include plural references. The meaning of "in" includes "in" and "on."

The terms "substantially," "close," "approximately," "near," and "about" generally refer to being within +/- 10% of a target value. Unless otherwise specified the use of the ordinal adjectives "first," "second," and "third," etc., to describe a common object, merely indicate that different instances of like objects are being referred to, and are not intended to imply that the objects so described must be in a given sequence, either temporally, spatially, in ranking, or in any other manner.

It is to be understood that the terms so used are interchangeable under appropriate circumstances such that the embodiments of the invention described herein are, for example, capable of operation in other orientations than those illustrated or otherwise described herein. The terms "left," "right," "front," "back," "top," "bottom," "over," "under," and the like in the description and in the claims, if any, are used for descriptive purposes and not necessarily for describing permanent relative positions.

For purposes of the embodiments, the transistors in various circuits, modules, and logic blocks are Tunneling FETs (TFETs). Some transistors of various embodiments may comprise metal oxide semiconductor (MOS) transistors, which include drain, source, gate, and bulk terminals. The transistors may also include Tri-Gate and FinFET transistors, Gate All Around Cylindrical Transistors, Square Wire, or Rectangular Ribbon Transistors or other devices implementing transistor functionality like carbon nanotubes or spintronic devices. MOSFET symmetrical source and drain terminals i.e., are identical terminals and are interchangeably used here. A TFET device, on the other hand, has asymmetric Source and Drain terminals. Those skilled in the art will appreciate that other transistors, for example, Bi-polar junction transistors-BJT PNP/NPN, BiCMOS, CMOS, etc., may be used for some transistors without departing from the scope of the disclosure.

For the purposes of the present disclosure, the phrases "A and/or B" and "A or B" mean (A), (B), or (A and B). For the purposes of the present disclosure, the phrase "A, B, and/or C" means (A), (B), (C), (A and B), (A and C), (B and C), or (A, B and C).

In addition, the various elements of combinatorial logic and sequential logic discussed in the present disclosure may pertain both to physical structures (such as AND gates, OR gates, or XOR gates), or to synthesized or otherwise optimized collections of devices implementing the logical structures that are Boolean equivalents of the logic under discussion.

In addition, for purposes of the present disclosure, the terms "eNB," "AP," "5G eNB," "mmWave eNB," "mmWave small cell," and "base station" may be substantially interchangeable. For purposes of the present disclosure, "UE," "STA," "5G UE," and "mmWave UE," and "mobile equipment" may be substantially interchangeable.

In the various embodiments discussed below, an eNB and/or a UE may be calibrated for directional reciprocity. Accordingly, the same beam (and/or sector) may be both a best TX beam (and/or sector) and a best RX beam (and/or sector), and may have substantially the same Angle of Departure and Angle of Arrival. Moreover, some embodiments discussed below may employ a Time-Division Duplex (TDD) scheme, but other embodiments may employ another scheme such as a Frequency-Division Duplex (FDD) scheme.

1: Multi-Connectivity Network Architecture

Figure 1 shows the proposed multi-connectivity network architecture 100 according to examples. The examples are described in terms of the entities and links used in the 4G/LTE standards, but the principles may equally be applied to any other similar function entities in existing or newly proposed 5G systems and mmWave systems in particular. In Figure 1, there is a UE 110, connectable to eNBs 120-140 via Uu links 115, where Uu is the name for the standard radio interface between the UE and the eNode B. Meanwhile, the eNBs are connect to one another, for example via X2 interfaces 135, where X2 is the name for the standard radio interface between the eNode Bs. The eNBs are connected to the serving gateway (S-GW) 150 of the core network via respective S1 links 145. The S-GW 150 is connected to the rest of the core network via the Packet Data Network (PDN) - Gateway, P-GW 160 via suitable links, such as the S5 or S8 links 155.

In the example shown, a UE 110 may connect to multiple eNBs simultaneously, in this case eNBs #A 120, #B 130 and #C 140. In this Figure, there is shown a multi-connectivity arrangement where there is a single anchor eNB (eNB #A 120) and two booster eNBs (eNBs #B 130 and #C 140). Thus, in this arrangement, the UE 110 only has one anchor

eNB, and all other eNBs are booster, however other arrangements with multiples of each eNB type (anchor or booster), or a multiple of at least one type (e.g. boosters), may also be provided in other examples.

In this example, the anchor eNB #A 120 is responsible for all (i.e. both user-plane and control-plane) communications between the UE 110 and the core network (S-GW//P-GW/MME, etc.). This is shown in Figure 1 by the bold line for the central S1 interface between anchor eNB #A 120 and the S-GW 150.). Meanwhile, the booster eNBs (#B 130/#C 140) is/are only responsible for communications with UE in the RAN (i.e. responsible only for UE to eNB communications).

In the disclosed examples, the UE 110 may have multiple RAN connections, where a RAN connection is a communications link from the UE to a (possibly different) eNB. Whilst the anchor eNB will always control the UE's main link to the core network, the UE's RAN communications links may be classified as either a primary communications link 180 or a secondary communications link 190.

The UE 110 uses its primary communications links 180 to send and receive data traffic, and its secondary communications links 190 as back-up in case if/when (any of its primary communications links are lost). If UE 110 has multiple primary communications links, UE's 110 data traffic may be split over these primary communications links, i.e. a form of bearer splitting may be implemented. Where a secondary communications link is used by a UE 110, the respective user-plane/control-plane data may be sent to the anchor eNB 120 via a respective X2 link (i.e. forming an indirect link from the UE 110 to the core network)

A way to view the newly proposed system of Figure 1, as described above, is that it decouples the traditional anchor functionality to connect to the core network from the traditional anchor functionality of providing the air interface to the UE (as per the usual anchor-booster type arrangement). In this way, multiple secondary communications (air interface) links between the UE 110 and respective (secondary, booster type) eNBs (e.g. #B 130, #C 140) may be used (each being carried to the anchor eNB (e.g. #A 120) via an X2 link 135. Another way to view this is that there is a single point/path of entry to/from the UE 110 from the core network point of view, but multiple points/paths of entry to/from the UE 110, from the UE point of view. The following description and examples therein detail how this arrangement may provide benefits, and may be used to provide new functionality not available to previous directional communications systems.

Figure 2 shows an example of a possible end to end (e2e) user-plane protocol stack 200 for the proposed multi-connectivity network architecture of Figure 1.

In this Figure, there is shown a UE 110 connected to three eNBs – an anchor eNB #A 120, and two booster eNBs - #B 130 and #C 140. The anchor eNB #A 120 acts as the UE's
5 main/only link to the core network (i.e. all other UE traffic, which may be served in the RAN by the other booster eNBs, must still route through this anchor eNB). The booster eNBs - #B 130 and #C 140, act to only provide RAN access to the UE and sends all the UE traffic to/from the core network via the anchor eNB #A 120 (via, e.g. the X2 interfaces 135).

The UE connects to each of the eNBs via a respective one of the usual UE-eNB
10 interfaces (often referenced the Uu interface) 115. The eNBs connect to each other over the usual eNB to eNB interfaces (often referenced the X2 interface).

In a UE 110 according to the present disclosure, there is provided a new multi-connectivity control entity in the protocol stack, which is being called the Multi-Connectivity
Convergence Protocol. This is shown, for the UE (for user-plane portion) as entity MCCP-u
15 111. This is located in the UE's protocol stack between the IP layer, and the PDCP layer for each connection in use (three are shown in this figure, but there could be more or less in other implementations).

A similar complementary eNB-side MCCP-u entity 121 is shown in the anchor eNB
#A 120. In the user-plane (i.e. user data), there may be no need for a MCCP-u protocol entity
20 in the booster eNBs, since they are only passing data along to the anchor eNB according to the control of the MCCP-c protocol entities discussed below.

The rest of the disclosed protocol entities, e.g. the PDCP, RLC, PHY/MAC, GTP-U, UDP and IP entities all operate in their usual way, and are therefore not described in any
further detail here.

25 Figure 3 shows an example of a possible end to end (e2e) control-plane protocol stack 300 for the proposed multi-connectivity network architecture of Figure 1.

As shown in this figure, each of the eNBs and the UE 110 now also include a Multi-Connectivity Convergence Protocol control-plane layer entity (MCCP-c), which are shown as
items UE MCCP-c 112, eNB #A MCCP-c 122, eNB #B MCCP-c 132, and eNB #C MCCP-c
30 142, respectively. These are provided at each location, because control of data and control flow may be carried out (or at least implemented) at any or all of their locations.

Again, the rest of the disclosed protocol entities, e.g. the NAS, PDCP, RLC, PHY/MAC, GTP-U, UDP, IP, and RRC entities all operate in their usual way, and are therefore again not described in any further detail here.

In these figures, the UE 110 may send or receive data traffic via its anchor eNB 120 directly, or via its booster eNB (130, 150), which then communicate with the anchor eNB 20 over the X2 interface 135. The proposed multi-connectivity convergence u-plane protocol (MCCP-u) operates above/over the individual RAN stacks (above PDCP), and it may manage how a UE's 110 data traffic are routed over multiple primary links 180. Unlike in the 3GPP R13 dual-connectivity solution, all communications links between the UE and the respective eNBs (i.e. both primary and secondary Uu links) have their own complete user-plane and control-plane stack, and therefore may operate independently to one another. In some examples, support for above PDCP bearer splitting in the proposed MCCP may be provided. Also, in some examples, neighboring eNBs may coordinate with each other, for example via the X2 Application Protocol, that may be run over the X2 interface between eNBs.

2: Inter-Cell Coordination for Synchronization and Sector Level Sweep (SLS)

Since it may be difficult to achieve tight symbol level synchronization between mmWave cells, examples may have all the neighboring mmWave cells coordinate with each other in order to maintain a fixed offset between when each SLS is allocated in neighbouring eNBs, i.e. provide what is called herein an "SLS Start Offset". An explanation of this may be as follows. Let's use D_k to indicate the "SLS Start Offset" for cell #k, where:

$$D_k = k \times T_{\text{offset}}, \text{ where } k = 1 \sim N \quad (1)$$

According to an example, the eNB should broadcast the parameters (k , N , T_{offset}) to the UE 110 as part of the system information sent in the DL control channel, so that the UE 110 knows in which superframe/frame/subframe a respective synchronization signal (e.g. Primary Synchronization Signal (PSS)/Secondary Synchronization Signal (SSS)/ Sector Level Sweep (SLS) signal) may be transmitted in its neighboring cells. If neighboring cells are tightly synchronized at the Cyclic Prefix (CP) level, then the UE 110 can synchronize with all neighboring cells simultaneously with the same clock and we may configure $T_{\text{offset}} = 0$ such that the SLS signals from neighboring cells occurs at the same time. Tight synchronization may be defined as any timing difference between cells/eNBs of a symbol or less, such as 10% of a symbol transmission time.

Otherwise, if cells are loosely synchronized at the symbol level, which is a more likely use-case scenario, the UE 110 may keep a separate clock and timing regime for each of

the cells/eNBs that it connects to. In which case, T_{offset} may be configured to be a value > 0 such that the UE 110 can perform SLS for different cells at different times, i.e. this may provide a form of Time Division Multiplex (TDM) of the SLS process. In this case, N determines the maximum number of eNBs that a UE 110 can connect to simultaneously.

- 5 Figure 4 shows a first optional example of how PSS/SSS/SLS signals from neighboring cells may be distributed in a frame with $N = 3$ and $T_{\text{offset}} = 1$ subframe.

In particular, Figure 4 shows a timeline for how PSS, SSS, and SLS signals may be allocated in neighboring cells. In Figure 4, we show SLS (sector level sweep) allocations for UE (receiver) sector sweep signals (RXSS) and eNB (transmitter) sector sweep signals (TXSS) respectively, where PSS 422/432/442 and SLS 428/438/448 are the eNB (transmitter) sector sweep signals (TXSS), while SSS 424/434/444 and SLS 426/436/446 are UE (receiver) sector sweep signals (RXSS).

The PSS and SSS signals are used for initial acquisition, and the SLS signal are used after initial acquisition is completed successfully and respective UE is attached. In this example, notice that all the PSS signals (e.g. PSS 422/432/442) always occurs before the SSS signals (e.g. SSS 424/434/444). Previously, the UE RXSS would occur during SSS and eNB TXSS would occur during PSS. However, in this example, all PSS or SSS in neighboring cells occurs at the same time, while respective SLS occurs with a fixed time offset, T_{offset} 435 (or multiples thereof for higher numbered cells, e.g. $2T_{\text{offset}}$ 445). Note that the PSS/SSS signals are only needed during initial acquisition, and this is why they may occur in the same (e.g. first) subframe.

Figure 5 shows a second optional example of how PSS/SSS/SLS signals from neighboring cells may be distributed in a frame with $N = 3$ and $T_{\text{offset}} = 1$ subframe. In Figure 5, we show SLS allocations for UE RXSS and eNB TXSS respectively, where PSS 522/532/542 and SLS 528/538/548 are eNB TXSS, while SSS 524/534/544 and SLS 526/536/546 are UE RXSS.

In particular, Figure 5 shows a timeline for offsetting the PSS, SSS, and SLS signals in neighboring cells.

Notice that the offset, T_{offset} 535 (or multiples thereof for higher numbered cells, e.g. $2T_{\text{offset}}$ 545), is simply being applied to the entire frame, which is a simpler arrangement to that shown in Figure 4.

3: Enhanced Downlink Control Channel for Link Loss Detection

The Physical Downlink Control Channel (PDCCH) occupies the first few symbols of a subframe, and so it can be used by the UE 110 to detect communications link loss.

However, the eNB may not be able to send the PDCCH sufficiently often to prevent a link loss being assumed detected at the UE 110 when using the PDCCH alone to detect

5 communications link loss. For example, where an eNB is sectorized, it may not be able to send the PDCCH over all its sectors simultaneously due to the link budget (i.e. wireless resources) constraints. In such situations, some examples may provide that the eNB may use all its RF chains together to send the PDCCH signal over each sector, one at a time.

For example, the eNB may have two sectors: A and B, and two UEs: a and b. UE #a
10 may connect to eNB via sector #A; UE #b may connect to eNB via sector #B. Here, it may be assumed that the eNB can only send the PDCCH over sector A or B at a time, but not both. In this example, if the eNB has lots of data traffic for UE #a, eNB will send the PDCCH over sector #A in consecutive frames to schedule UE #a's traffic. As a result, eNB won't send the PDCCH over sector #B for a period of time, so that the UE may mistakenly detect
15 communications link loss if it only relies on the receipt of the PDCCH.

To provide advantages for this sort of situation, according to examples of the present disclosure, a new downlink broadcast channel (or another control channel, such as a Beam Reference Signal (BRS)) may be used. In the following this shall be named the shortened Broadcast CHannel (sBCH), but any other name may equally be used. The sBCH may be
20 allocated to the available wireless resources, such as subframe, after the PDCCH (if indeed it is allocated). The actual allocation of the sBCH in time and frequency within a subframe may be configured through the (e.g. broadcasted) system information. The length of the sBCH may vary, but, the maximum may be fixed (denoted as N), and provided to UEs as part of system information. The sBCH may indicate the Cell ID and other resource parameter, such
25 as the relevant sector index. In the sBCH, the relevant eNB may send the same symbol repeatedly, for example over the selected sectors. By way of explanation of this process, let's define the following parameters:

T_{sBCH} : the sBCH/BRS interval;

K: the number of symbols in the PDCCH;

30 N: the maximum number of symbols of the sBCH/BRS;

m: link loss detection threshold;

Figure 6 shows how the sBCH may be allocated 600 in a subframe with three sectors: A, B, and C. In this example, PDCCH 610 is sent over sector #A to schedule the UE's traffic

on this sector (i.e. the PDCCH is only to schedule for the sector which it is using) and the sBCH 620 is sent over sectors #B and #C for link loss detection.

The sBCH 620 have value $n = 2$, since it is sent over two sectors in this example. Other values of n may be used, and will depend on the number of other sectors involved.

5 Meanwhile, the respective downlink data then follows 640 the PDCCH/sBCH in the usual way. According to the example structure of the sBCH of Figure 6, an example proposed PDCCH/sBCH based link loss detection procedure may work as follows:

Step 1: If the primary eNB #A 120 has not sent the PDCCH or sBCH over a sector in the last T_{sBCH} subframes, the eNB 120 may send the PDCCH over the sector if nothing
10 prevents it from doing so; otherwise, the eNB 120 may send sBCH over the sector after the first K symbols, and the PDCCH (sent over a different sector) may also indicate that the first n symbols (where $n \leq N$) after the PDCCH (i.e. after the end of the PDCCH) is reserved for the sBCH;

Step 2: the UE 110 receives the first K symbols of every subframe for PDCCH from
15 its respective primary eNBs. If the UE 110 does not receive these first K symbols of every subframe for PDCCH from its primary eNBs correctly, it may continue to receive the next N symbols for the sBCH. If the UE 110 has not received the PDCCH or sBCH from its primary eNB in last $m \times T_{\text{sBCH}}$ subframes, then the UE 110 can assume its connection to the respective primary eNB is lost.

20 The primary eNB #A 120 may broadcast $(m, K, N, T_{\text{sBCH}})$ to the UE 110 as part of system information.

In some alternative examples, a new enhanced (cell-specific) Reference Signal (eRS) may be persistently allocated for every Transmit Time Interval (TTI). The eRS's time and frequency allocation information may also be provided in the system information, and may be
25 mapped to a sector index, and the eRS itself may also carry the Cell ID information. Thus, the UE 110 can detect communications link loss directly by measuring eRS. If the UE has not received eRS from its last $m \times T_{\text{eRS}}$ subframes, then the UE 110 can assume its connection to the respective primary eNB is lost.

The foregoing is described in an example deployment using an eNB with sectors, as
30 this is a more typical arrangement with the directional nature of mmWave communications. However, the principles of the present disclosure may equally be applied in deployments not utilising sectors.

4: persistent Scheduling Request (pSR) allocation for secondary control link

After the UE 110 detects link loss in its primary cell (i.e. as being served by eNB #A 120), the UE 110 needs to switch over to one of its secondary cells (e.g. as served by eNBs #B 130 or #C 140) as quickly as possible. This may be achieved using a light-weight scheduling request procedure as now described, according to examples of the present disclosure. The proposed light-weight scheduling request procedure may provide the advantage that the UE 110 may maintain UpLink (UL) synchronization with its secondary cell, and also send out the request to switch the primary cell via the secondary control link. Similarly to LTE, the UE's 110 persistent Scheduling Request (pSR) in the secondary cell may also be persistently allocated. In some examples, the pSR may be sent every Transmit Time Interval (TTI), although in other examples the pSR may be sent less regularly, e.g. at/on intervals of more than one TTI. Altering the regularity of sending the pSR may affect time to detection, but less regular sending is more wireless resource efficient. Thus, the pSR transmission interval may be use-case specific.

In addition, the UE's 110 primary eNB (e.g. eNB #A 120) may coordinate with its secondary eNB (e.g. eNB #B 130) to reconfigure the UE's 110 pSR in the secondary cell. Moreover, in some examples, a new way to indicate how the pSR is allocated may be provided, which can be used for a normal subframe or a special subframe in which Downlink (DL) synchronization or a broadcast channel (e.g. the PSS/SSS/ Broadcast Channel (BCH)) occupies the last few symbols of a subframe. According to such examples, the following parameters may be defined:

$d_{\text{pSR-REQ}}$: the offset in terms of symbols between the first symbols of the persistent Scheduling Request message sent on the Uplink (i.e. pSR REQ message (UL)) and the last symbol that can be used for DL/UL allocation (excluding PSS/SSS/BCH allocation) in the respective subframe;

$d_{\text{pSR-RSP}}$: the offset in terms of symbols between the first symbols of the pSR REQ message (UL) and the first symbol of the pSR RSP message (DL);

T_{pSR} : the cycle time of the persistent Scheduling Request (in terms of slots/subframes), i.e. how often a persistent Scheduling Request is sent in a subframe – for example, it may be every subframe (which is very reactive to link loss, but not wireless resource efficient, or it may be every x subframes, e.g. 10 subframes, which is a more efficient use of the wireless resources available, but is a trade off on reactivity to acting on the link loss;

Figure 7 shows how the pSR-REQ and pSR-RSP messages may be allocated in a subframe, around the PDCCH, PSS/SSS/BCH, etc of a special subframe, while Figure 8 shows how the pSR-REQ and pSR-RSP messages may be allocated in a normal subframe. The main point of these figures is to show that the persistent Scheduling Request (pSR) is scheduling in a persistent place in the respective subframe, set by the parameters: $d_{\text{pSR-REQ}}$ 730, $d_{\text{pSR-RSP}}$ 740, and T_{pSR} . Notably, the persistent scheduling seeks to place the pSR at a point referenced from the last symbol that can be used for UE-specific resource allocation, which is from the end of the respective subframe (for normal subframe), or from the last $N + 1$ symbol of the subframe if the last N symbols are used for PSS, SSS, BCH, or SLS, or any other signals (for special subframe). In any case, the UE's 110 primary eNB (e.g. eNB #A 120) may coordinate with a secondary eNB(s) (e.g. eNB #B 130 or #C 140) to reconfigure UE's pSR ($d_{\text{pSR-REQ}}$, $d_{\text{pSR-RSP}}$, T_{pSR}).

5: Fast Cell Switching (FCS) Procedure

Figure 9 shows a high level flow diagram of a method 900 of detecting communications link loss according to an example.

The method may be preceded by a respective primary eNB sending 905 the sBCH broadcast parameters discussed above to the UE, for example in the system information.

At step 910, the UE can seek to detect whether its (respective, or at least a one of its respective) primary communications link(s) with the primary eNB has been lost (i.e. blocked) through use of the PDCCH, sBCH or the eRS signals, as discussed in detail above. In particular, the loss of a communications link may be determined by the incorrect or non-receipt of the respective control signal (PDCCH, sBCH or eRS). If this happens, the result of the 'correct receipt test' is negative 925, so the method moves to step 930, which determines the respective primary communications link is lost, and so instigates the fast switching cell procedure, for example, as discussed in detail below, with respect to Figure 10.

If the 'correct receipt test' test result is positive, 915, the primary connection is OK 920 and may continue to be used. The test 910 may then repeat in due course.

Figure 10 shows, in more detail, some key steps in a method 1000 for the UE 110 to switch its primary cell, according to a FCS procedure according to some example embodiments.

In the example of Figure 10, it is assumed the UE 110 is connected to one anchor eNB (#A) 120 (i.e. the eNB currently primary) and two booster eNBs – eNB #B 130 (i.e. a first currently secondary eNB) and eNB #C 140 (i.e. a second currently secondary eNB), and that the secondary eNB that will be made the primary is eNB #B 130.

At the very beginning, the anchor eNB (#A) 120 is primary, and the booster eNB (#B) 130 is secondary. The UE 110 is configured with the periodic pSR 1010 from eNB #B 130 so that it can maintain UL synchronization in the secondary cell while transferring data in the primary cell. The UE transfers data in the primary cell using communications links provided to the UE by the primary cell eNB. The periodicity of the periodic pSR is set by the parameter T_{pSR} .

During the use of the primary communications links, while they are still working normally (i.e. not considered lost or broken), the PDCCH/sBCH/eRS are transmitted 1020 by the primary eNB #A 120 and correctly received by the UE 110. This is to say the UE 110 continues to receive the PDCCH or the sBCH, or the eRS, from its primary eNB (#A) 120 and the pSR from the secondary eNB (#B) 130.

However, when the UE 110 fails to correctly receive any one or more of the PDCCH, sBCH or eRS, as discussed above, the primary communications links between the UE and the primary eNB are considered lost or broken. This is shown by the crosses 1025 for the second and third PDCCH/sBCH/eRS transmissions 1020. This may be carried out within a time frame defined by $m \times T_{\text{sBCH}}$, as shown, and discussed in detail above. When the UE 110 detects communications link loss, it may trigger the FCS procedure 1040 (see more details in the above section 3).

Meanwhile, the UE 110 continues to receive the pSR signals from the secondary cell eNB, but can only act to request a transfer of the data being sent over the (now lost) primary communication link to a working 'hot swap' secondary communications link provided by a secondary eNB (e.g. eNB #B 130) at the next allocated pSR transmission.

Once the FCS procedure 1040 is triggered, the UE 110 selects one of its secondary eNBs (in this case, as noted above, eNB #B 130) as its new primary eNB based on for example received signal strength or other measurements, and go to step 4.

Therefore, the UE 110 can send out the FCS REQ message (e.g. as part of pSR-REQ) to the selected secondary eNB (eNB #B 130) at 1050.

The selected eNB (eNB #B 130) will respond to the FCS REQ message received from the UE 110 with the FCS RSP message (e.g. as part of pSR-RSP) to confirm the switching at 1060.

The old secondary eNB #B 130 is now the new primary eNB. Thus, wireless UE-eNB interface traffic/data (i.e. that to be sent between the respective UE and "the wireless

network” (= an eNB)) will now be sent to the new primary eNB, and that may be routed to the core-network via the anchor eNB if the new primary is not the anchor eNB.

Next, the new primary eNB (eNB #B 130) will send the FCS notification message to the anchor eNB (eNB #A 120) at 1070, so that it can update its information and start to
5 forward DL traffic to the new primary eNB (eNB #B 130), e.g. via the X2 interface.

At 1080, the new primary eNB (eNB #B 130) may initiate a sector selection procedure so that the UE 110 can select the most appropriate sector of eNB #b 130 to use for data transfer in the new primary cell.

It will be appreciated that in some examples, only a single secondary eNB may be
10 involved, or more than two. In the former case, the selection is simple (i.e. the system merely choose “the other one”, whereas, in the latter case, there may be a suitable selection methodology applied to select the best secondary eNB to use as the primary. The present disclosure is not limited in this respect. Examples of selection methodology may include, but not be limited to: cell capacity, cell signal quality, cell signal strength, cell
15 frequency, etc.

Figure 11 illustrates an eNB and a UE, in accordance with some embodiments of the disclosure. Figure 11 includes block diagrams of an eNB 1110 and a UE 1130 which are operable to co-exist with each other and other elements of an LTE network. High-level, simplified architectures of eNB 1110 and UE 1130 are described so as not to obscure the
20 embodiments. It should be noted that in some embodiments, eNB 1110 may be a stationary non-mobile device.

eNB 1110 is coupled to one or more antennas 1105, and UE 1130 is similarly coupled to one or more antennas 1125. However, in some embodiments, eNB 1110 may incorporate or comprise antennas 1105, and UE 1130 in various embodiments may incorporate or
25 comprise antennas 1125.

In some embodiments, antennas 1105 and/or antennas 1125 may comprise one or more directional or omni-directional antennas, including monopole antennas, dipole antennas, loop antennas, patch antennas, microstrip antennas, coplanar wave antennas, or other types of antennas suitable for transmission of RF signals. In some MIMO (multiple-input and
30 multiple output) embodiments, antennas 1105 are separated to take advantage of spatial diversity.

eNB 1110 and UE 1130 are operable to communicate with each other on a network, such as a wireless network. eNB 1110 and UE 1130 may be in communication with each

other over a wireless communication channel 1150, which has both a downlink path from eNB 1110 to UE 1130 and an uplink path from UE 1130 to eNB 1110.

As illustrated in Figure 11, in some embodiments, eNB 1110 may include a physical layer circuitry 1112, a MAC (media access control) circuitry 1114, a processor 1116, a memory 1118, and a hardware processing circuitry 1120. A person skilled in the art will appreciate that other components not shown may be used in addition to the components shown to form a complete eNB.

In some embodiments, physical layer circuitry 1112 includes a transceiver 1113 for providing signals to and from UE 1130. Transceiver 1113 provides signals to and from UEs or other devices using one or more antennas 1105. In some embodiments, MAC circuitry 1114 controls access to the wireless medium. Memory 1118 may be, or may include, a storage media/medium such as a magnetic storage media (e.g., magnetic tapes or magnetic disks), an optical storage media (e.g., optical discs), an electronic storage media (e.g., conventional hard disk drives, solid-state disk drives, or flash-memory-based storage media), or any tangible storage media or non-transitory storage media. Hardware processing circuitry 1120 may comprise logic devices or circuitry to perform various operations. In some embodiments, processor 1116 and memory 1118 are arranged to perform the operations of hardware processing circuitry 1120, such as operations described herein with reference to logic devices and circuitry within eNB 1110 and/or hardware processing circuitry 1120. Accordingly, in some embodiments, eNB 1110 may be a device comprising an application processor, a memory, one or more antenna ports, and an interface for allowing the application processor to communicate with another device.

As is also illustrated in Figure 11, in some embodiments, UE 1130 may include a physical layer circuitry 1132, a MAC circuitry 1134, a processor 1136, a memory 1138, a hardware processing circuitry 1140, a wireless interface 1142, and a display 1144. A person skilled in the art would appreciate that other components not shown may be used in addition to the components shown to form a complete UE.

In some embodiments, physical layer circuitry 1132 includes a transceiver 1133 for providing signals to and from eNB 1110 (as well as other eNBs). Transceiver 1133 provides signals to and from eNBs or other devices using one or more antennas 1125. In some embodiments, MAC circuitry 1134 controls access to the wireless medium. Memory 1138 may be, or may include, a storage media/medium such as a magnetic storage media (e.g., magnetic tapes or magnetic disks), an optical storage media (e.g., optical discs), an electronic

storage media (e.g., conventional hard disk drives, solid-state disk drives, or flash-memory-based storage media), or any tangible storage media or non-transitory storage media.

Wireless interface 1142 may be arranged to allow the processor to communicate with another device. Display 1144 may provide a visual and/or tactile display for a user to interact with
5 UE 1130, such as a touch-screen display. Hardware processing circuitry 1140 may comprise logic devices or circuitry to perform various operations. In some embodiments, processor 1136 and memory 1138 may be arranged to perform the operations of hardware processing circuitry 1140, such as operations described herein with reference to logic devices and circuitry within UE 1130 and/or hardware processing circuitry 1140.

10 Accordingly, in some embodiments, UE 1130 may be a device comprising an application processor, a memory, one or more antennas, a wireless interface for allowing the application processor to communicate with another device, and a touch-screen display. Elements of Figure 11, and elements of other figures having the same names or reference numbers, can operate or function in the manner described herein with respect to any such
15 figures (although the operation and function of such elements is not limited to such descriptions).

In addition, although eNB 1110 and UE 1130 are each described as having several separate functional elements, one or more of the functional elements may be combined and may be implemented by combinations of software-configured elements and/or other hardware
20 elements. In some embodiments of this disclosure, the functional elements can refer to one or more processes operating on one or more processing elements. Examples of software and/or hardware configured elements include Digital Signal Processors (DSPs), one or more microprocessors, DSPs, Field-Programmable Gate Arrays (FPGAs), Application Specific Integrated Circuits (ASICs), Radio-Frequency Integrated Circuits (RFICs), and so on.

25 An eNB may include various hardware processing circuitries discussed herein, which may in turn comprise logic devices and/or circuitry operable to perform various operations. For example, with reference to Figure 11, eNB 1110 (or various elements or components therein, such as hardware processing circuitry 1120, or combinations of elements or components therein) may include part of, or all of, these hardware processing circuitries.

30 In some embodiments, one or more devices or circuitries within these hardware processing circuitries may be implemented by combinations of software-configured elements and/or other hardware elements. For example, processor 1116 (and/or one or more other processors which eNB 1110 may comprise), memory 1118, and/or other elements or

components of eNB 1110 (which may include hardware processing circuitry 1120) may be arranged to perform the operations of these hardware processing circuitries, such as operations described herein with reference to devices and circuitry within these hardware processing circuitries. In some embodiments, processor 1116 (and/or one or more other
5 processors which eNB 1110 may comprise) may be a baseband processor.

Similarly, a UE may include various hardware processing circuitries discussed herein, which may in turn comprise logic devices and/or circuitry operable to perform various operations. For example, with reference to Figure 11, UE 1130 (or various elements or components therein, such as hardware processing circuitry 1140, or combinations of elements
10 or components therein) may include part of, or all of, these hardware processing circuitries. In some embodiments, one or more devices or circuitries within these hardware processing circuitries may be implemented by combinations of software-configured elements and/or other hardware elements. For example, processor 1136 (and/or one or more other processors which UE 1130 may comprise), memory 1138, and/or other elements or components of UE
15 1130 (which may include hardware processing circuitry 1140) may be arranged to perform the operations of these hardware processing circuitries, such as operations described herein with reference to devices and circuitry within these hardware processing circuitries. In some embodiments, processor 1136 (and/or one or more other processors which UE 1130 may comprise) may be a baseband processor.

Various methods described herein may relate to eNB 1110 and hardware processing circuitry 1120. Although the actions in the herein described methods are shown in a particular order, the order of the actions can be modified. Thus, the illustrated embodiments can be performed in a different order, and some actions may be performed in parallel. Some of the actions and/or operations listed may be optional in accordance with certain
20 embodiments. The numbering of the actions presented is for the sake of clarity and is not intended to prescribe an order of operations in which the various actions must occur. Additionally, operations from the various flows may be utilized in a variety of combinations. Moreover, in some embodiments, machine readable storage media may have executable instructions that, when executed, cause eNB 1110 and/or hardware processing circuitry 1120
30 to perform an operation comprising any of the described methods. Such machine readable storage media may include any of a variety of storage media, like magnetic storage media (e.g., magnetic tapes or magnetic disks), optical storage media (e.g., optical discs), electronic

storage media (e.g., conventional hard disk drives, solid-state disk drives, or flash-memory-based storage media), or any other tangible storage media or non-transitory storage media. In some embodiments, an apparatus may comprise means for performing various actions and/or operations of the methods.

5 Similarly, various methods that may relate to UE 1130 and hardware processing circuitry 1140 are also described herein. Again, although the actions may be shown in a particular order, the order of the actions can be modified. Thus, the illustrated embodiments can be performed in a different order, and some actions may be performed in parallel. Some of the actions and/or operations carried out by the UE are optional in accordance with certain
10 embodiments. The numbering of the actions presented is for the sake of clarity and is not intended to prescribe an order of operations in which the various actions must occur. Additionally, operations from the various flows may be utilized in a variety of combinations.

Moreover, in some embodiments, machine readable storage media may have executable instructions that, when executed, cause UE 1130 and/or hardware processing
15 circuitry 1140 to perform an operation comprising any of the disclosed methods. Such machine readable storage media may include any of a variety of storage media, like magnetic storage media (e.g., magnetic tapes or magnetic disks), optical storage media (e.g., optical discs), electronic storage media (e.g., conventional hard disk drives, solid-state disk drives, or flash-memory-based storage media), or any other tangible storage media or non-transitory
20 storage media.

Embodiments described herein may be implemented into a system using any suitably configured hardware and/or software. Figure 12 shows, for one embodiment, example components of an electronic device 1200. In embodiments, the electronic device 1200 may be, implement, be incorporated into, or otherwise be a part of a user equipment (UE), an
25 evolved NodeB (eNB), or another network component (e.g. a network component corresponding to a network virtualization device and/or a software defined network device). In some embodiments, the electronic device 1200 may include application circuitry 1210, baseband circuitry 1220, Radio Frequency (RF) circuitry 1230, front-end module (FEM) circuitry 1240 and one or more antennas 1250, coupled together at least as shown.

30 The application circuitry 1210 may include one or more application processors. For example, the application circuitry 1210 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The processor(s) may include any combination of general-purpose processors and dedicated processors (e.g., graphics

processors, application processors, etc.). The processors may be coupled with and/or may include memory/storage and may be configured to execute instructions stored in the memory/storage to enable various applications and/or operating systems to run on the system.

The baseband circuitry 1220 may include circuitry such as, but not limited to, one or
5 more single-core or multi-core processors. The baseband circuitry 1220 may include one or more baseband processors and/or control logic to process baseband signals received from a receive signal path of the RF circuitry 1230 and to generate baseband signals for a transmit signal path of the RF circuitry 1230. Baseband processing circuitry 1220 may interface with the application circuitry 1210 for generation and processing of the baseband signals and for
10 controlling operations of the RF circuitry 1230. For example, in some embodiments, the baseband circuitry 1220 may include a second generation (2G) baseband processor 1221, third generation (3G) baseband processor 1222, fourth generation (4G) baseband processor 1223, and/or other baseband processor(s) 1224 for other existing generations, generations in development or to be developed in the future (e.g., fifth generation (5G), 6G, etc.). The
15 baseband circuitry 1220 (e.g., one or more of baseband processors 1221-1224) may handle various radio control functions that enable communication with one or more radio networks via the RF circuitry 1230. The radio control functions may include, but are not limited to, signal modulation/demodulation, encoding/decoding, radio frequency shifting, etc. In some embodiments, modulation/demodulation circuitry of the baseband circuitry 1220 may include
20 Fast-Fourier Transform (FFT), precoding, and/or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 1220 may include convolution, tail-biting convolution, turbo, Viterbi, and/or Low Density Parity Check (LDPC) encoder/decoder functionality. Embodiments of modulation/demodulation and encoder/decoder functionality are not limited to these
25 examples and may include other suitable functionality in other embodiments.

In some embodiments, the baseband circuitry 1220 may include elements of a protocol stack such as, for example, elements of an evolved universal terrestrial radio access network (EUTRAN) protocol including, for example, physical (PHY), media access control (MAC), radio link control (RLC), packet data convergence protocol (PDCP), radio resource
30 control (RRC) elements and/or the disclosed MCCP layer protocol. A central processing unit (CPU) 1225 of the baseband circuitry 1220 may be configured to run elements of the protocol stack for signaling of the PHY, MAC, RLC, PDCP, RRC and/or MCCP Layers. In some embodiments, the baseband circuitry may include one or more audio digital signal

processor(s) (DSP) 1226. The audio DSP(s) 1226 may include elements for compression/decompression and echo cancellation and may include other suitable processing elements in other embodiments.

The baseband circuitry 1220 may further include memory/storage 1227. The
5 memory/storage 1227 may be used to load and store data and/or instructions for operations performed by the processors of the baseband circuitry 1220. Memory/storage for one embodiment may include any combination of suitable volatile memory and/or non-volatile memory. The memory/storage 1227 may include any combination of various levels of memory/storage including, but not limited to, read-only memory (ROM) having embedded
10 software instructions (e.g., firmware), random access memory (e.g., dynamic random access memory (DRAM)), cache, buffers, etc. The memory/storage 1227 may be shared among the various processors or dedicated to particular processors.

Components of the baseband circuitry may be suitably combined in a single chip, a single chipset, or disposed on a same circuit board in some embodiments. In some
15 embodiments, some or all of the constituent components of the baseband circuitry 1220 and the application circuitry 1210 may be implemented together such as, for example, on a system on a chip (SOC).

In some embodiments, the baseband circuitry 1220 may provide for communication compatible with one or more radio technologies. For example, in some
20 embodiments, the baseband circuitry 1220 may support communication with an evolved universal terrestrial radio access network (EUTRAN) and/or other wireless metropolitan area networks (WMAN), a wireless local area network (WLAN), a wireless personal area network (WPAN). Embodiments in which the baseband circuitry 1220 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode
25 baseband circuitry.

RF circuitry 1230 may enable communication with wireless networks using modulated electromagnetic radiation through a non-solid medium. In various embodiments, the RF circuitry 1230 may include switches, filters, amplifiers, etc. to facilitate the communication with the wireless network. RF circuitry 1230 may include a receive
30 signal path which may include circuitry to down-convert RF signals received from the FEM circuitry 1240 and provide baseband signals to the baseband circuitry 1220. RF circuitry 1230 may also include a transmit signal path which may include circuitry to up-convert baseband

signals provided by the baseband circuitry 1220 and provide RF output signals to the FEM circuitry 1240 for transmission.

In some embodiments, the RF circuitry 1230 may include a receive signal path and a transmit signal path. The receive signal path of the RF circuitry 1230 may include mixer circuitry 1231, amplifier circuitry 1232 and filter circuitry 1233. The transmit signal path of the RF circuitry 1230 may include filter circuitry 1233 and mixer circuitry 1231. RF circuitry 1230 may also include synthesizer circuitry 1234 for synthesizing a frequency for use by the mixer circuitry 1231 of the receive signal path and the transmit signal path. In some embodiments, the mixer circuitry 1231 of the receive signal path may be configured to down-convert RF signals received from the FEM circuitry 1240 based on the synthesized frequency provided by synthesizer circuitry 1234. The amplifier circuitry 1232 may be configured to amplify the down-converted signals and the filter circuitry 1233 may be a low-pass filter (LPF) or band-pass filter (BPF) configured to remove unwanted signals from the down-converted signals to generate output baseband signals. Output baseband signals may be provided to the baseband circuitry 1220 for further processing. In some embodiments, the output baseband signals may be zero-frequency baseband signals, although this is not a requirement. In some embodiments, mixer circuitry 1231 of the receive signal path may comprise passive mixers, although the scope of the embodiments is not limited in this respect.

In some embodiments, the mixer circuitry 1231 of the transmit signal path may be configured to up-convert input baseband signals based on the synthesized frequency provided by the synthesizer circuitry 1232 to generate RF output signals for the FEM circuitry 1240. The baseband signals may be provided by the baseband circuitry 1220 and may be filtered by filter circuitry 1233. The filter circuitry 1233 may include a low-pass filter (LPF), although the scope of the embodiments is not limited in this respect.

In some embodiments, the mixer circuitry 1231 of the receive signal path and the mixer circuitry 1231 of the transmit signal path may include two or more mixers and may be arranged for quadrature downconversion and/or upconversion respectively. In some embodiments, the mixer circuitry 1231 of the receive signal path and the mixer circuitry 1231 of the transmit signal path may include two or more mixers and may be arranged for image rejection (e.g., Hartley image rejection). In some embodiments, the mixer circuitry 1231 of the receive signal path and the mixer circuitry 1231 may be arranged for direct downconversion and/or direct upconversion, respectively. In some embodiments, the mixer

circuitry 1231 of the receive signal path and the mixer circuitry 1231 of the transmit signal path may be configured for super-heterodyne operation.

In some embodiments, the output baseband signals and the input baseband signals may be analog baseband signals, although the scope of the embodiments is not limited in this respect. In some alternate embodiments, the output baseband signals and the input baseband signals may be digital baseband signals. In these alternate embodiments, the RF circuitry 1230 may include analog-to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry and the baseband circuitry 1220 may include a digital baseband interface to communicate with the RF circuitry 1230.

In some dual-mode embodiments, a separate radio IC circuitry may be provided for processing signals for each spectrum, although the scope of the embodiments is not limited in this respect.

In some embodiments, the synthesizer circuitry 1234 may be a fractional-N synthesizer or a fractional $N/N+1$ synthesizer, although the scope of the embodiments is not limited in this respect as other types of frequency synthesizers may be suitable. For example, synthesizer circuitry 1234 may be a delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider.

The synthesizer circuitry 1234 may be configured to synthesize an output frequency for use by the mixer circuitry 1231 of the RF circuitry 1230 based on a frequency input and a divider control input. In some embodiments, the synthesizer circuitry 1234 may be a fractional $N/N+1$ synthesizer.

In some embodiments, frequency input may be provided by a voltage controlled oscillator (VCO), although that is not a requirement. Divider control input may be provided by either the baseband circuitry 1220 or the applications processor 1210 depending on the desired output frequency. In some embodiments, a divider control input (e.g., N) may be determined from a look-up table based on a channel indicated by the applications processor 1210.

Synthesizer circuitry 1234 of the RF circuitry 1230 may include a divider, a delay-locked loop (DLL), a multiplexer and a phase accumulator. In some embodiments, the divider may be a dual modulus divider (DMD) and the phase accumulator may be a digital phase accumulator (DPA). In some embodiments, the DMD may be configured to divide the input signal by either N or $N+1$ (e.g., based on a carry out) to provide a fractional division ratio. In some example embodiments, the DLL may include a set of cascaded, tunable, delay

elements, a phase detector, a charge pump and a D-type flip-flop. In these embodiments, the delay elements may be configured to break a VCO period up into N_d equal packets of phase, where N_d is the number of delay elements in the delay line. In this way, the DLL provides negative feedback to help ensure that the total delay through the delay line is one VCO cycle.

5 In some embodiments, synthesizer circuitry 1234 may be configured to generate a carrier frequency as the output frequency, while in other embodiments, the output frequency may be a multiple of the carrier frequency (e.g., twice the carrier frequency, four times the carrier frequency) and used in conjunction with quadrature generator and divider circuitry to generate multiple signals at the carrier frequency with multiple different phases with respect
10 to each other. In some embodiments, the output frequency may be a LO frequency (f_{LO}). In some embodiments, the RF circuitry 1230 may include an IQ/polar converter.

FEM circuitry 1240 may include a receive signal path which may include circuitry configured to operate on RF signals received from one or more antennas 1250, amplify the received signals and provide the amplified versions of the received signals to the RF circuitry
15 1230 for further processing. FEM circuitry 1240 may also include a transmit signal path which may include circuitry configured to amplify signals for transmission provided by the RF circuitry 1230 for transmission by one or more of the one or more antennas 1250.

In some embodiments, the FEM circuitry 1240 may include a TX/RX switch to switch between transmit mode and receive mode operation. The FEM circuitry may include a
20 receive signal path and a transmit signal path. The receive signal path of the FEM circuitry may include a low-noise amplifier (LNA) to amplify received RF signals and provide the amplified received RF signals as an output (e.g., to the RF circuitry 1230). The transmit signal path of the FEM circuitry 1240 may include a power amplifier (PA) to amplify input RF signals (e.g., provided by RF circuitry 1230), and one or more filters to generate RF
25 signals for subsequent transmission (e.g., by one or more of the one or more antennas 1250).

In various embodiments, network interface controller (NIC) circuitry 1260 may include one or more transmission and reception (TX/RX) signal paths, which may connect to one or more data packet networks via network interface circuitry 1265. In some
embodiments, NIC circuitry 1260 may connect to the data packet networks via multiple
30 network interface circuitries 1265. The NIC circuitry 1260 may support one or more data link Layer standards, such as Ethernet, Fiber, Token Ring, asynchronous transfer mode (ATM), and/or any other suitable data link Layer standard(s). In some embodiments, each network element that the electronic device 1200 may connect to (for example, a base station, network

controller, a radio access network (RAN) device, a S-GW, SDN switch, MME, P-GW, and the like) may contain a same or similar network interface circuitry 1265. Furthermore, the NIC circuitry 1260 may include, or may be associated with processing circuitry, such as one or more single-core or multi-core processors and/or logic circuits, to provide processing techniques suitable to carry out communications according to the one or more data link Layer standards used by the NIC circuitry.

In some embodiments, the electronic device 1200 may include additional elements such as, for example, memory/storage, display, camera, sensor, and/or input/output (I/O) interface.

10 In some embodiments, the electronic device of Figure 12 may be configured to perform one or more processes, techniques, and/or methods as described herein, or portions thereof.

Figure 13 is a block diagram illustrating components, according to some example embodiments, able to read instructions from a machine-readable or computer-readable medium (e.g., a machine-readable storage medium) and perform any one or more of the methodologies discussed herein. Specifically, Figure 13 shows a diagrammatic representation of hardware resources 1300 including one or more processors (or processor cores) 1310, one or more memory/storage devices 1320, and one or more communication resources 1330, each of which are communicatively coupled via a bus 1340.

20 The processors 1310 (e.g., a central processing unit (CPU), a reduced instruction set computing (RISC) processor, a complex instruction set computing (CISC) processor, a graphics processing unit (GPU), a digital signal processor (DSP) such as a baseband processor, an application specific integrated circuit (ASIC), a radio-frequency integrated circuit (RFIC), another processor, or any suitable combination thereof) may include, for example, a processor 1312 and a processor 1314. The memory/storage devices 1320 may include main memory, disk storage, or any suitable combination thereof.

The communication resources 1330 may include interconnection and/or network interface components or other suitable devices to communicate with one or more peripheral devices 1304 and/or one or more databases 1306 via a network 1308. For example, the communication resources 1330 may include wired communication components (e.g., for coupling via a Universal Serial Bus (USB)), cellular communication components, Near Field Communication (NFC) components, Bluetooth® components (e.g., Bluetooth® Low Energy), Wi-Fi® components, and other communication components.

Instructions 1350 may comprise software, a program, an application, an applet, an app, or other executable code for causing at least any of the processors 1310 to perform any one or more of the methodologies discussed herein. The instructions 1350 may reside, completely or partially, within at least one of the processors 1310 (e.g., within the processor's
5 cache memory), the memory/storage devices 1320, or any suitable combination thereof. Furthermore, any portion of the instructions 1350 may be transferred to the hardware resources 1300 from any combination of the peripheral devices 1304 and/or the databases 1306. Accordingly, the memory of processors 1310, the memory/storage devices 1320, the peripheral devices 1304, and the databases 1306 are examples of computer-readable and
10 machine-readable media.

While the above-described examples may be used in the context of a 5G RAT for licensed frequency bands, the principles covered are general and are as easily applicable for alternative designs. For example, examples of the present disclosure may be applied to alternate mmWave access systems such as WiGig/802.11ay or potentially to any other
15 massive Multiple-Input-Multiple-Output (MIMO) systems, particularly those utilizing directional acquisition/any signals (control or data) of a directional nature.

Similarly, whilst the above-described examples are optimizations described in the context of a specific frame structure, the principles covered have general applicability and may be applied with alternative frame structures or multi-access schemes.

According to examples described herein, there may be provided a new Multi-Connectivity network architecture and c-plane/u-plane protocol stack operable to support an efficient "hot standby" configuration between primary and secondary cells, the "hot standby" configuration allowing for fast transitions of control and data traffic between cells upon communications link loss of a main (i.e. primary) communications link.
20

According to examples described herein, there may be provided a new inter-cell coordination method for synchronized PSS/SSS/SLS.
25

According to examples described herein, there may be provided a new broadcast channel (e.g. shortened BCH) or enhanced reference signal (eRS) for fast communications link loss detection. Specific examples may utilize more than one of the new broadcast
30 channels or reference signals, or even the PDCCH to detect communications link loss. According to examples described herein, there may be provided a new method to support persistent allocation of scheduling request(s) in subframe(s) with or without PSS/SSS/SLS/BCH (i.e. normal or special subframes).

According to examples described herein, there may be provided a new SR (Scheduling Request)-based fast cell switching (FCS) procedure / protocol.

Examples of the present disclosure may be used in future 3GPP standards (R14 and beyond).

5 Reference in the specification to "an embodiment," "one embodiment," "some embodiments," or "other embodiments" means that a particular feature, structure, or characteristic described in connection with the embodiments is included in at least some embodiments, but not necessarily all embodiments. The various appearances of "an embodiment," "one embodiment," or "some embodiments" are not necessarily all referring to
10 the same embodiments. If the specification states a component, feature, structure, or characteristic "may," "might," or "could" be included, that particular component, feature, structure, or characteristic is not required to be included. If the specification or claim refers to "a" or "an" element, that does not mean there is only one of the elements. If the specification or claims refer to "an additional" element, that does not preclude there being
15 more than one of the additional element.

 Furthermore, the particular features, structures, functions, or characteristics may be combined in any suitable manner in one or more embodiments. For example, a first embodiment may be combined with a second embodiment anywhere the particular features, structures, functions, or characteristics associated with the two embodiments are not mutually
20 exclusive.

 While the disclosure has been described in conjunction with specific embodiments thereof, many alternatives, modifications and variations of such embodiments will be apparent to those of ordinary skill in the art in light of the foregoing description. For example, other memory architectures e.g., Dynamic RAM (DRAM) may use the
25 embodiments discussed. The embodiments of the disclosure are intended to embrace all such alternatives, modifications, and variations as to fall within the broad scope of the appended claims.

 In addition, well known power/ground connections to integrated circuit (IC) chips and other components may or may not be shown within the presented figures, for simplicity of
30 illustration and discussion, and so as not to obscure the disclosure. Further, arrangements may be shown in block diagram form in order to avoid obscuring the disclosure, and also in view of the fact that specifics with respect to implementation of such block diagram arrangements are highly dependent upon the platform within which the present disclosure is

to be implemented (i.e., such specifics should be well within purview of one skilled in the art). Where specific details (e.g., circuits) are set forth in order to describe example embodiments of the disclosure, it should be apparent to one skilled in the art that the disclosure can be practiced without, or with variation of, these specific details. The description is thus to be regarded as illustrative instead of limiting.

The following examples pertain to further embodiments. Specifics in the examples may be used anywhere in one or more embodiments. All optional features of the apparatus described herein may also be implemented with respect to a method or process.

Example 1 may include an apparatus of a User Equipment (UE) operable to communicate with an Evolved Node-B (eNB) on a wireless network, comprising: one or more processors to: maintain a plurality of radio access network communications links between the UE and at least two eNBs of a radio access network of the wireless network, wherein at least a first eNB is an anchor eNB and wherein at least a second eNB is a booster eNB, said plurality of radio access network communications links between the UE and a radio access network of the wireless network comprising at least one primary communications link and at least one secondary communications link; and switch between actively using the at least one primary communications link for sending and receiving data of the UE to actively using the at least one secondary communications link for sending and receiving data of the UE when the at least one primary communications link is determined to be lost; wherein the anchor eNB is operable to provide both communications between the UE and a core network serving the wireless network, and communications between the UE and a radio access network providing the wireless network; and wherein the booster eNB is operable to provide communications between the UE and the radio access network providing the wireless network, and is operable to communicate with the core network only via the anchor eNB.

Example 2 may include the apparatus of example 1 or any other example herein, wherein the anchor eNB provides both user-plane and control-plane communications between the UE and the core network.

Example 3 may include the apparatus of example 1 or 2, or any other example herein, wherein the booster eNB provides both user-plane and control-plane communications between the UE and the anchor eNB. Another example may include the apparatus of any other example, wherein the booster eNB provides both user-plane and control-plane communications between the UE and the core network.

Example 4 may include the apparatus of any of examples 1 to 3, or any other example herein, wherein the booster eNB communicates with the anchor eNB over an eNB to eNB communications link interface, optionally an X2 interface.

Example 5 may include the apparatus of any of examples 1 to 4, or any other example
5 herein, wherein the UE maintains at least two primary communications links, and wherein the one or more processors are further to split traffic to be sent between the at least two primary communications links.

Example 6 may include the apparatus of example 5, or any other example herein, wherein to split traffic to be sent between the at least two primary communications links comprises
10 providing at least two bearer links, wherein a bearer link is assigned to each primary communications link.

Example 7 may include the apparatus of any of examples 1 to 6, or any other example herein, wherein the one or more processors are further to: provide a multi-connectivity convergence protocol (MCCP) stack entity, wherein the MCCP stack entity operates above individual
15 radio access network protocol sub-stacks, and wherein the MCCP stack entity manages how the UE data traffic is routed over the primary and secondary communications links.

Example 8 may include the apparatus of any of examples 1 to 7, or any other example herein, wherein to operate above individual radio access network protocol sub-stacks comprises operating above the packet data convergence protocol (PDCP) stack entity of each wireless
20 communications link(s) operating in the UE.

Example 9 may include the apparatus of any of examples 1 to 8, or any other example herein, wherein each wireless communications link(s) operating in the UE comprises an independent user-plane and control-plane stack to provide operation independent from each other wireless communications link(s) operating in the UE.

Example 10 may include the apparatus of any of examples 1 to 9, or any other example
25 herein, wherein the one or more processors are further to provide PDCP bearer splitting by the MCCP stack entity.

Example 11 may include the apparatus of any of examples 7 to 10, or any other example herein, wherein the MCCP stack entity comprises a user-plane portion, MCCP-u, and a
30 control-plane portion, MCCP-c.

Example 12 may include a UE device comprising an application processor, a memory, one or more antennas, a wireless interface for allowing the application processor to communicate

with another device, and a touch-screen display, the UE device including the apparatus of any of examples 1 to 11.

Example 13 may include a machine readable storage media having machine executable
5 instructions that, when executed, cause one or more processors to perform an operation in a User Equipment (UE) operable to communicate with an Evolved Node-B (eNB) on a wireless network, comprising: maintaining a plurality of radio access network communications links between the UE and at least two eNBs of a radio access network of the wireless network, wherein at least a first eNB is an anchor eNB and wherein at least a second eNB is a booster
10 eNB, said plurality of radio access network communications links between the UE and a radio access network of the wireless network comprising at least one primary communications link and at least one secondary communications link; and switching between actively using the at least one primary communications link for sending and receiving data of the UE to actively using the at least one secondary communications link for sending and
15 receiving data of the UE when the at least one primary communications link is determined to be lost.

Example 14 may include the machine readable storage media of example 13, or any other example herein, further comprising: maintaining at least two primary communications links; and splitting traffic to be sent between the at least two primary communications links.

20 Example 15 may include the machine readable storage media of example 13 or 14, or any other example herein, further comprising providing at least two bearer links, wherein a bearer link is assigned to each primary communications link.

Example 16 may include the machine readable storage media of any of examples 13 to 15, or any other example herein, further comprising: providing a multi-connectivity convergence
25 protocol (MCCP) stack entity operating above individual radio access network protocol sub-stacks; and managing how the UE data traffic is routed over the primary and secondary communications links using the MCCP stack entity.

Example 17 may include the machine readable storage media of example 16, or any other example herein, wherein operating above individual radio access network protocol sub-stacks
30 comprises operating above the packet data convergence protocol (PDCP) stack entity of each wireless communications link(s) provided in the UE.

Example 18 may include the machine readable storage media of any of examples 13 to 17, or any other example herein, further comprising providing an independent user-plane and

control-plane stack for each independent wireless communications link(s) provided in the UE.

Example 19 may include the machine readable storage media of any of examples 13 to 18, or any other example herein, further comprising providing PDCP bearer splitting by the MCCP stack entity.

Example 20 may include the machine readable storage media of any of examples 16 to 18, wherein the MCCP stack entity comprises a user-plane portion, MCCP-u, and a control-plane portion, MCCP-c.

Example 21 may include a method in a User Equipment (UE) operable to communicate with an Evolved Node-B (eNB) on a wireless network, comprising: connecting and communicating with at least two eNBs, wherein at least a first eNB is an anchor eNB and wherein at least a second eNB is a booster eNB; maintaining a plurality of radio access network communications links between the UE and a radio access network of the wireless network, said plurality of radio access network communications links between the UE and a radio access network of the wireless network comprising at least one primary communications link and at least one secondary communications link; switching between actively using the at least one primary communications link for sending and receiving data of the UE to actively using the at least one secondary communications link for sending and receiving data of the UE when the at least one primary communications link is determined to be lost.

Example 22 may include the method of example 21, or any other example herein, further comprising: maintaining at least two primary communications links; and splitting traffic to be sent between the at least two primary communications links.

Example 23 may include the method of example 21 or 22, or any other example herein, further comprising providing at least two bearer links, wherein a bearer link is assigned to each primary communications link.

Example 24 may include the method of any of examples 21 to 23, or any other example herein, further comprising: providing a multi-connectivity convergence protocol (MCCP) stack entity operating above individual radio access network protocol sub-stacks; and managing how the UE data traffic is routed over the primary and secondary communications links using the MCCP stack entity.

Example 25 may include the method of example 24, or any other example herein, wherein operating above individual radio access network protocol sub-stacks comprises operating

above the packet data convergence protocol (PDCP) stack entity of each wireless communications link(s) provided in the UE.

Example 26 may include the method of any of examples 21 to 25, or any other example herein, further comprising providing an independent user-plane and control-plane stack for
5 each independent wireless communications link(s) provided in the UE.

Example 27 may include the method of any of examples 21 to 26, or any other example herein, further comprising providing PDCP bearer splitting by the MCCP stack entity.

Example 28 may include the method of any of examples 24 to 27, or any other example herein, wherein the MCCP stack entity comprises a user-plane portion, MCCP-u, and a
10 control-plane portion, MCCP-c.

Example 29 may include an apparatus of an Evolved Node-B (eNB) operable to communicate with a User Equipment (UE) on a wireless network, comprising: one or more processors to: selectably operate the eNB in a first operational state that acts as an anchor eNB to at least one UE, wherein operating as the anchor eNB comprises providing
15 communications between the at least one UE and a core network serving the wireless network; and selectably operate the eNB in a second operational state that acts as a booster eNB to the at least one UE, wherein operating as the booster eNB comprises providing communications between the at least one UE and a radio access network of the wireless network; wherein the one or more processors are further to: select between the first and
20 second operational states based upon information from the at least one UE.

Another example may include the eNB of example 29, or any other example herein, wherein to select (or selecting) between the first and second operational states based upon information from the at least one UE may comprise any one or more of: based on a specified data or a specified signal received from the UE (e.g. based on data from the System Information, or the signals sBCH, eRS, PDCCH); based on receiving or otherwise processing a specified data or
25 a specified signal from the UE (e.g. based on receiving or otherwise processing data from the System Information, or the signals sBCH, eRS, PDCCH); based on not receiving or not otherwise processing a specified data or a specified signal from the UE (e.g. based on not receiving or not otherwise processing data from the System Information, or the signals sBCH,
30 eRS, PDCCH).

In examples, the radio access network of the wireless network may comprise at least one cell, optionally a small cell.

Example 30 may include the apparatus of example 29, or any other example herein, wherein the anchor eNB provides both user-plane and control-plane communications between the at least one UE and a core network.

Example 31 may include the apparatus of example 29 or 30, or any other example herein,
5 wherein the booster eNB provides both user-plane and control-plane communications between the at least one UE and the anchor eNB.

Example 32 may include the apparatus of any of examples 29 to 31, or any other example herein, wherein the booster eNB communicates with the anchor eNB over an eNB to eNB communications link interface, optionally an X2 interface.

10 Example 33 may include the apparatus of any of examples 29 to 32, or any other example herein, wherein the eNB provides at least two primary communications links with the at least one UE, and wherein the one or more processors are further to split traffic to be sent between the at least two primary communications links.

Example 34 may include the apparatus of example 33, or any other example herein,
15 to split traffic to be sent between the at least two primary communications links comprises providing at least two bearer links, wherein a bearer link is assigned to each primary communications link.

Example 35 may include the apparatus of any of examples 29 to 34, or any other example herein, wherein the one or more processors are further to: provide a multi-connectivity
20 convergence protocol (MCCP) stack entity, wherein the MCCP stack entity operates above individual radio access network protocol sub-stacks, and wherein the MCCP stack entity manages how the at least one UE's data traffic is routed over the primary and secondary communications links.

Example 36 may include the apparatus of any of examples 29 to 35, or any other example
25 herein, wherein to operate above individual radio access network protocol sub-stacks comprises operating above the packet data convergence protocol (PDCP) stack entity of each wireless communications link(s) operating in the eNB.

Example 37 may include the apparatus of any of examples 29 to 36, or any other example herein, wherein each wireless communications link(s) operating in the eNB comprises an
30 independent user-plane and control-plane stack to provide operation independent from each other wireless communications link(s) operating in the eNB.

Example 38 may include the apparatus of any of examples 29 to 37, or any other example herein, wherein the one or more processors are further to provide PDCP bearer splitting by the MCCP stack entity.

Example 39 may include the apparatus of any of examples 29 to 38, or any other example
5 herein, wherein the MCCP stack entity comprises a user-plane portion, MCCP-u, and a control-plane portion, MCCP-c.

Example 40 may include an eNB device comprising an application processor, a memory, one or more antenna ports, and an interface for allowing the application processor to communicate with another device, the eNB device including the apparatus of any of
10 examples 29 through 39.

Example 41 may include machine readable storage media having machine executable instructions that, when executed, cause one or more processors to perform an operation in an Evolved Node-B (eNB) operable to communicate with a User Equipment (UE) on a wireless network, comprising: selectably operating the eNB in a first operational state that acts as an
15 anchor eNB to at least one UE, wherein operating as the anchor eNB comprises providing communications between the at least one UE and a core network serving the wireless network; and selectably operating the eNB in a second operational state that acts as a booster eNB to the at least one UE, wherein operating as the booster eNB comprises providing communications between the at least one UE and a radio access network of the wireless
20 network; select between the first and second operational states based upon information from the at least one UE.

Example 42 may include the machine readable storage media of example 41, or any other example herein, further comprising providing both user-plane and control-plane communications between the at least one UE and a core network.

Example 43 may include the machine readable storage media of example 41 or 42, or any
25 other example herein, further comprising providing, by the booster eNB, both user-plane and control-plane communications between the at least one UE and the anchor eNB.

Example 44 may include the machine readable storage media of any of examples 41 to 43, or any other example herein, further comprising communicating with the anchor eNB by the
30 booster eNB over an eNB to eNB communications link interface, optionally an X2 interface.

Example 45 may include the machine readable storage media of any of examples 41 to 44, or any other example herein, further comprising: providing at least two primary communications

links with the at least one UE; and splitting traffic to be sent between the at least two primary communications links.

Example 46 may include the machine readable storage media of example 45, or any other example herein, wherein splitting traffic to be sent between the at least two primary
5 communications links comprises providing at least two bearer links, wherein a bearer link is assigned to each primary communications link.

Example 47 may include the machine readable storage media of any of examples 41 to 46, or any other example herein, further comprising providing a multi-connectivity convergence protocol (MCCP) stack entity, wherein the MCCP stack entity operates above individual
10 radio access network protocol sub-stacks and wherein the MCCP stack entity manages how the at least one UE's data traffic is routed over the primary and secondary communications links.

Example 48 may include the machine readable storage media of any of examples 41 to 47, or any other example herein, wherein operating above individual radio access network protocol
15 sub-stacks comprises operating above the packet data convergence protocol (PDCP) stack entity of each wireless communications link(s) operating in the eNB.

Example 49 may include the machine readable storage media of any of examples 41 to 48, or any other example herein, further comprising providing an independent user-plane and control-plane stack for each other wireless communications link(s) operating in the eNB.

Example 50 may include the machine readable storage media of any of examples 41 to 49, or any other example herein, further comprising providing PDCP bearer splitting by the MCCP
20 stack entity.

Example 51 may include the machine readable storage media of any of examples 41 to 50, or any other example herein, further comprising providing a user-plane portion, MCCP-u, and a
25 control-plane portion, MCCP-c, of the MCCP stack entity.

Example 52 may include a method in an Evolved Node-B (eNB) operable to communicate with a User Equipment (UE) on a wireless network, comprising: selectably operating the eNB in a first operational state that acts as an anchor eNB to at least one UE, wherein operating as the anchor eNB comprises providing communications between the at least one UE and a core
30 network serving the wireless network; and selectably operating the eNB in a second operational state that acts as a booster eNB to the at least one UE, wherein operating as the booster eNB comprises providing communications between the at least one UE and a radio

access network of the wireless network; selecting between the first and second operational states based on information from the at least one UE.

Example 53 may include the method of example 52, or any other example herein, further comprising providing both user-plane and control-plane communications between the at least
5 one UE and a core network.

Example 54 may include the method media of example 52 or 53, or any other example herein, further comprising providing, by the booster eNB, both user-plane and control-plane communications between the at least one UE and the anchor eNB.

Example 55 may include the method of any of examples 51 to 54, or any other example
10 herein, further comprising communicating with the anchor eNB by the booster eNB over an eNB to eNB communications link interface, optionally an X2 interface.

Example 56 may include the method of any of examples 52 to 55, or any other example herein, further comprising: providing at least two primary communications links with the at least one UE; and splitting traffic to be sent between the at least two primary communications
15 links.

Example 57 may include the method of example 56, or any other example herein, wherein splitting traffic to be sent between the at least two primary communications links comprises providing at least two bearer links, wherein a bearer link is assigned to each primary communications link.

Example 58 may include the method of any of examples 52 to 57, or any other example
20 herein, further comprising providing a multi-connectivity convergence protocol (MCCP) stack entity, wherein the MCCP stack entity operates above individual radio access network protocol sub-stacks and wherein the MCCP stack entity manages how the at least one UE's data traffic is routed over the primary and secondary communications links.

Example 59 may include the method of any of examples 52 to 58, or any other example
25 herein, wherein operating above individual radio access network protocol sub-stacks comprises operating above the packet data convergence protocol (PDCP) stack entity of each wireless communications link(s) operating in the eNB.

Example 60 may include the method of any of examples 52 to 59, or any other example
30 herein, further comprising providing an independent user-plane and control-plane stack for each other wireless communications link(s) operating in the eNB.

Example 61 may include the method of any of examples 52 to 60, or any other example herein, further comprising providing PDCP bearer splitting by the MCCP stack entity.

Example 62 may include the method of any of examples 52 to 61, or any other example herein, further comprising providing a user-plane portion, MCCP-u, and a control-plane portion, MCCP-c, of the MCCP stack entity.

Example 63 may include machine readable storage media having machine executable instructions that, when executed, cause one or more processors to perform an operation to synchronize neighboring cells using directional transmissions comprising: coordinating the neighboring cells to maintain a fixed offset between the transmission of Evolved Node-B (eNB) control signals, wherein the control signals comprises: a Primary Synchronization Signal (PSS) transmission corresponding to one or more first eNB transmit-and-receive sectors; a Secondary Synchronization Signal (SSS) transmission corresponding to one or more second eNB transmit-and-receive sectors, as received through one or more UE transmit-and-receive sectors; and a Sector Level Sweep (SLS) signal; and wherein coordinating the neighboring cells comprises: broadcasting offset information to a UE, wherein the offset information includes a neighboring cell ID, k , a maximum number of neighboring cells, N , involved and a fixed time offset, T_{offset} , for use by a neighboring cell identified by k .

Example 64 may include the machine readable storage media of example 63, or any other example herein, wherein the fixed time offset, T_{offset} , is set to zero if the neighboring cells are tightly synchronized, wherein tightly synchronized comprises being synchronized to a symbol or less time period.

Example 65 may include the machine readable storage media of example 63 or 64, or any other example herein, wherein, if the neighboring cells are not tightly synchronized, wherein tightly synchronized comprises being synchronized to a symbol or less time period, the method further comprises maintaining a separate timing regime for each neighboring cells that is not tightly synchronized.

Example 66 may include the machine readable storage media of example 65, or any other example herein, wherein maintaining a separate timing regime for each neighboring cell comprises maintaining a separate timer clock for each neighboring cell.

Example 67 may include the machine readable storage media of any of examples 63 to 66, or any other example herein, further comprising transmitting consecutively the Primary

Synchronization Signal (PSS) transmission and the Secondary Synchronization Signal (SSS) transmission in a first subframe transmission of each neighboring cell and using the fixed time offset, T_{offset} , to delay a subsequent transmission of the Sector Level Sweep (SLS) signal for each neighboring cell, wherein an overall delay of a given cell N is a k multiple of the

fixed time offset, T_{offset} ; wherein the first subframe transmission of each neighboring cell containing the Primary Synchronization Signal (PSS) transmission and the Secondary Synchronization Signal (SSS) transmission are sent simultaneously across all neighboring cells.

5 Example 68 may include the machine readable storage media of any of examples 63 to 67, or any other example herein, further comprising consecutively transmitting the Primary Synchronization Signal (PSS) transmission, the Secondary Synchronization Signal (SSS) transmission and the Sector Level Sweep (SLS) signal in a first subframe transmission of each neighboring cell, wherein the fixed time offset, T_{offset} , delays the transmission of the first
10 subframe of each neighboring cell respective to one another, wherein the neighboring cell k delays the transmission of its first subframe by $k \times$ the fixed time offset, T_{offset} .

Example 69 may include the machine readable storage media of any of examples 63 to 68, or any other example herein, wherein Sector Level Sweep (SLS) comprises an exhaustive search to select a best transmit sector on an eNB for a UE, wherein SLS is performed by both
15 transmitter and receiver.

Example 70 may include a method to synchronize neighboring cells using directional transmissions comprising: coordinating the neighboring cells to maintain a fixed offset between the transmission of Evolved Node-B (eNB) control signals, wherein the control signals comprises: a Primary Synchronization Signal (PSS) transmission corresponding to
20 one or more first eNB transmit-and-receive sectors; a Secondary Synchronization Signal (SSS) transmission corresponding to one or more second eNB transmit-and-receive sectors, as received through one or more UE transmit-and-receive sectors; and a Sector Level Sweep (SLS) signal; and wherein coordinating the neighboring cells comprises: broadcasting offset information to a UE, wherein the offset information includes a neighboring cell ID, k , a
25 maximum number of neighboring cells, N , involved and a fixed time offset, T_{offset} , for use by a neighboring cell identified by k .

Example 71 may include the method of example 70, or any other example herein, further comprising setting the fixed time offset, T_{offset} , to zero if the neighboring cells are tightly synchronized, wherein tightly synchronized comprises being synchronized to a symbol or less
30 time period.

Example 72 may include the method of example 70 or 71, or any other example herein, wherein, if the neighboring cells are not tightly synchronized, wherein tightly synchronized comprises being synchronized to a symbol or less time period, the method further comprises

maintaining a separate timing regime for each neighboring cells that is not tightly synchronized.

Example 73 may include the method of example 72, or any other example herein, wherein maintaining a separate timing regime for each neighboring cell comprises maintaining a
5 separate timer clock for each neighboring cell.

Example 74 may include the method of any of examples 70 to 73, or any other example herein, further comprising: transmitting consecutively the Primary Synchronization Signal (PSS) transmission and the Secondary Synchronization Signal (SSS) transmission in a first subframe transmission of each neighboring cell; using the fixed time offset, T_{offset} , to delay a
10 subsequent transmission of the Sector Level Sweep (SLS) signal for each neighboring cell, wherein an overall delay of a given cell N is a k multiple of the fixed time offset, T_{offset} ; and sending, simultaneously in the first subframe transmission of each neighboring cell, the Primary Synchronization Signal (PSS) transmission and the Secondary Synchronization Signal (SSS) transmission across all neighboring cells.

Example 75 may include the method of any of examples 70 to 73, or any other example herein, further comprising: consecutively transmitting the Primary Synchronization Signal (PSS) transmission, the Secondary Synchronization Signal (SSS) transmission and the Sector Level Sweep (SLS) signal in a first subframe transmission of each neighboring cell; wherein the fixed time offset, T_{offset} , delays the transmission of the first subframe of each neighboring
20 cell respective to one another, wherein the neighboring cell k delays the transmission of its first subframe by k x the fixed time offset, T_{offset} .

Example 76 may include the method of any of examples 70 to 75, or any other example herein, wherein Sector Level Sweep (SLS) comprises an exhaustive search to select a best transmit sector on an eNB for a UE, wherein SLS is performed by both transmitter and
25 receiver.

Example 77 may include machine readable storage media having machine executable instructions that, when executed, cause one or more processors to perform an operation in a UE to detect a communications link loss, comprising: receiving communications over a communications link; and determining the communications link is lost (or broken) by
30 determining incorrect receipt of at least one of a plurality of predetermined communications types over the communications link; wherein the plurality of predetermined communications type comprises: a Physical Downlink Control Channel (PDCCH); a dedicated link loss detection broadcast located in a subframe portion to be received after the PDCCH, having a

set of link loss detection broadcast parameters; and an enhanced Reference Signal (eRS) persistently allocated for every one or a fixed number of Transmit Time Intervals (TTIs) associated with the communications link; and wherein incorrect receipt of the PDCCH, dedicated link loss detection broadcast or enhanced Reference Signal comprises not
5 receiving the PDCCH, dedicated link loss detection broadcast or enhanced Reference Signal on given sector of an evolved Node-B (eNB) within a predetermined time period.

Example 78 may include the machine readable storage media of example 77, or any other example herein, wherein the eRS is mapped onto a predetermined sector of an eNB.

Example 79 may include the machine readable storage media of example 77 or 78, or any
10 other example herein, wherein the eRS includes cell ID information.

Example 80 may include the machine readable storage media of any of examples 77 to 79, or any other example herein, wherein time and frequency allocations of wireless resources of the eRS are mapped to an eNB sector index.

Example 81 may include a method in a UE to detect a communications link loss, comprising:
15 receiving communications over a communications link; and determining the communications link is lost (or broken) by determining incorrect receipt of at least one of a plurality of predetermined communications types over the communications link; wherein the plurality of predetermined communications type comprises: a Physical Downlink Control Channel (PDCCH); a dedicated link loss detection broadcast located in a subframe portion to be
20 received after the PDCCH, having a set of link loss detection broadcast parameters; and an enhanced Reference Signal (eRS) persistently allocated for every one or a fixed number of Transmit Time Intervals (TTIs) associated with the communications link; and wherein incorrect receipt of the PDCCH, dedicated link loss detection broadcast or enhanced Reference Signal comprises not receiving the PDCCH, dedicated link loss detection
25 broadcast or enhanced Reference Signal on given sector of an evolved Node-B (eNB) within a predetermined time period.

Example 82 may include the method of example 81, or any other example herein, wherein the eRS is mapped onto a predetermined sector of an eNB.

Example 83 may include the method of example 81 or 82, or any other example herein,
30 wherein the eRS includes cell ID information.

Example 84 may include the method of any of examples 82 to 83, or any other example herein, wherein time and frequency allocations of wireless resources of the eRS are mapped to an eNB sector index.

Example 85 may include an apparatus of a User Equipment (UE) operable to communicate with an Evolved Node-B (eNB) on a wireless network, comprising: one or more processors to: process communication signals received over a communications link; and determine the communications link is lost (or broken) by determining incorrect receipt of at least one of a plurality of predetermined communications types over the communications link; wherein the plurality of predetermined communications type comprises: a Physical Downlink Control Channel (PDCCH); a dedicated link loss detection broadcast located in a subframe portion to be received after the PDCCH, having a set of link loss detection broadcast parameters; and an enhanced Reference Signal (eRS) persistently allocated for every one for fixed number of Transmit Time Intervals (TTIs) associated with the communications link; and wherein incorrect receipt of the PDCCH, dedicated link loss detection broadcast or enhanced Reference Signal comprises not receiving the PDCCH, dedicated link loss detection broadcast or enhanced Reference Signal on given sector of an evolved Node-B (eNB) within a predetermined time period.

Example 86 may include the apparatus of example 85, or any other example herein, wherein the eRS is mapped onto a predetermined sector of an eNB.

Example 87 may include the apparatus of example 85 or 86, or any other example herein, wherein the eRS includes cell ID information.

Example 88. The apparatus of any of examples 85 to 87, wherein time and frequency allocations of wireless resources of the eRS are mapped to an eNB sector index.

Example 89 may include machine readable storage media having machine executable instructions that, when executed, cause one or more processors to perform an operation in a User Equipment (UE) to detect a communications link loss, comprising: receiving a set of link loss detection broadcast parameters; and using the set of link loss detection broadcast parameters to detect receipt of the link loss detection broadcast; wherein the operation further comprises: determining a lost communications link associated with the link loss detection broadcast when the link loss detection broadcast is not correctly received; or determining the communications link associated with the link loss detection broadcast is operational when the link loss detection broadcast is correctly received; wherein the link loss detection broadcast parameters comprise: T_{SBCH} = a link loss detection broadcast interval; K = a number of symbols in the Physical Downlink Control Channel (PDCCH); N = a maximum number of symbols of the link loss detection broadcast; and M = a link loss detection threshold.

Example 90 may include the machine readable storage media of example 89, or any other example herein, wherein the link loss detection broadcast is allocated to wireless resources after the PDCCH.

Example 91 may include the machine readable storage media of example 89 or 90, or any
5 other example herein, wherein the wireless resources allocated to the link loss detection broadcast is configured through system information.

Example 92 may include the machine readable storage media of any of examples 89 to 91, or any other example herein, wherein the link loss detection broadcast has variable length, up to a maximum length provided to the UE in advance of receipt.

10 Example 93 may include the machine readable storage media of any of examples 89 to 92, or any other example herein, wherein the link loss detection broadcast comprises a cell identification (cell ID) and sector index.

Example 94 may include a method in a User Equipment (UE) to detect a communications link loss, comprising: receiving a set of link loss detection broadcast parameters; and using
15 the set of link loss detection broadcast parameters to detect receipt of the link loss detection broadcast; wherein the operation further comprises: determining a lost communications link associated with the link loss detection broadcast when the link loss detection broadcast is not correctly received; or determining the communications link associated with the link loss detection broadcast is operational when the link loss detection broadcast is correctly received;
20 wherein the link loss detection broadcast parameters comprise: T_{sBCH} = a link loss detection broadcast interval; K = a number of symbols in the Physical Downlink Control Channel (PDCCH); N = a maximum number of symbols of the link loss detection broadcast; and M = a link loss detection threshold.

Example 95 may include the method of example 94, or any other example herein, wherein the
25 link loss detection broadcast is allocated to wireless resources after the PDCCH.

Example 96 may include the method of example 94 or 95, or any other example herein, wherein the wireless resources allocated to the link loss detection broadcast is configured through system information.

Example 97 may include the method of any of examples 94 to 96, or any other example
30 herein, wherein the link loss detection broadcast has variable length, up to a maximum length provided to the UE in advance of receipt.

Example 98 may include the method of any of examples 94 to 97, or any other example herein, wherein the link loss detection broadcast comprises a cell identification (cell ID) and sector index.

Example 99 may include an apparatus of a User Equipment (UE) operable to communicate
5 with an Evolved Node-B (eNB) on a wireless network, comprising: one or more processors to: receive a set of link loss detection broadcast parameters; and use the set of link loss detection broadcast parameters to detect receipt of the link loss detection broadcast; determine a lost communications link associated with the link loss detection broadcast when the link loss detection broadcast is not correctly received; or determine the communications
10 link associated with the link loss detection broadcast is operational when the link loss detection broadcast is correctly received; wherein the link loss detection broadcast parameters comprise: T_{SBCH} = a link loss detection broadcast interval; K = a number of symbols in the Physical Downlink Control Channel (PDCCH); N = a maximum number of symbols of the link loss detection broadcast; and M = a link loss detection threshold.

Example 100 may include the apparatus of example 99, or any other example herein, wherein the link loss detection broadcast is allocated to wireless resources after the PDCCH.

In examples, wireless resources may comprise a portion of the subframe transmission, i.e. one or more Physical Resource Block(s).

Example 101 may include the apparatus of example 99 or 100, or any other example herein,
20 wherein the wireless resources allocated to the link loss detection broadcast is configured through system information.

Example 102 may include the apparatus of any of examples 99 to 101, or any other example herein, wherein the link loss detection broadcast has variable length, up to a maximum length provided to the UE in advance of receipt.

Example 103 may include the apparatus of any of examples 99 to 102, or any other example
25 herein, wherein the link loss detection broadcast comprises a cell identification (cell ID) and sector index.

Example 104 may include machine readable storage media having machine executable instructions that, when executed, cause one or more processors to perform an operation in an
30 Evolved Node-B (eNB) to detect a communications link loss, comprising: transmitting a set of link loss detection broadcast parameters; and transmitting a link loss detection broadcast in accordance with the set of link loss detection broadcast parameters; wherein the link loss detection broadcast parameters comprise: T_{SBCH} = a link loss detection broadcast interval; K

= a number of symbols in the Physical Downlink Control Channel (PDCCH); N = a maximum number of symbols of the link loss detection broadcast; and M = a link loss detection threshold.

Example 105 may include the machine readable storage media of example 104, or any other
5 example herein, wherein the link loss detection broadcast is allocated to wireless resources after or before the PDCCH.

Example 106 may include the machine readable storage media of example 104 or 105, or any other example herein, wherein the wireless resources allocated to the link loss detection broadcast is configured through system information.

10 Example 107 may include the machine readable storage media of any of examples 104 to 106, or any other example herein, wherein the link loss detection broadcast has variable length, up to a maximum length provided to a User Equipment (UE) in advance of receipt.

Example 108 may include the machine readable storage media of any of examples 104 to 107, or any other example herein, wherein the link loss detection broadcast comprises a cell
15 identification (cell ID) and sector index

Example 109 may include the machine readable storage media of any of examples 104 to 108, or any other example herein, wherein directional transmissions comprise millimeter wave transmissions.

Example 110 may include the machine readable storage media of any of examples 104 to
20 109, or any other example herein, wherein link loss detection broadcast parameters are sent via system information.

Example 111 may include the machine readable storage media of any of examples 104 to 110, or any other example herein, wherein the link loss detection broadcast comprises a shortened Broadcast CHannel (sBCH) or an enhanced Reference Signal (eRS) persistently
25 allocated for every Transmit Time Interval (TTI) associated with the communications link.

Example 112 may include the machine readable storage media of any of examples 104 to 111, or any other example herein, wherein persistently allocated comprises being allocated to persistent time and frequency wireless resources.

Example 113 may include a method in an Evolved Node-B (eNB) to detect a communications
30 link loss, comprising: transmitting a set of link loss detection broadcast parameters; and transmitting a link loss detection broadcast in accordance with the set of link loss detection broadcast parameters; wherein the link loss detection broadcast parameters comprise: T_{sBCH} = a link loss detection broadcast interval; K = a number of symbols in the Physical Downlink

Control Channel (PDCCH); N = a maximum number of symbols of the link loss detection broadcast; and M = a link loss detection threshold.

Example 114 may include the method of example 113, or any other example herein, further comprising allocating the link loss detection broadcast to wireless resources after or before the PDCCH.

Example 115 may include the method of example 113 or 114, or any other example herein, configuring the wireless resources allocated to the link loss detection broadcast through system information.

Example 116 may include the method of any of examples 113 to 115, or any other example herein, wherein the link loss detection broadcast has variable length, up to a maximum length provided to the UE in advance of receipt.

Example 117 may include the method of any of examples 113 to 116, or any other example herein, wherein the link loss detection broadcast comprises a cell identification (cell ID) and sector index

Example 118 may include the method of any of examples 113 to 117, or any other example herein, wherein directional transmissions comprise millimeter wave transmissions.

Example 119 may include the method of any of examples 113 to 118, or any other example herein, further comprising sending the link loss detection broadcast parameters via system information.

Example 120 may include the method of any of examples 113 to 119, or any other example herein, wherein the link loss detection broadcast comprises a shortened Broadcast CHannel (sBCH) or an enhanced Reference Signal (eRS) persistently allocated for every Transmit Time Interval (TTI) associated with the communications link.

Example 121 may include the method of any of examples 113 to 120, or any other example herein, wherein persistently allocated comprises being allocated to persistent time and frequency wireless resources.

Example 122 may include an apparatus of an evolved Node-B (eNB) operable to communicate with a User Equipment (UE) in a wireless network, comprising: one or more processors to: transmit a set of link loss detection broadcast parameters; and transmit a link loss detection broadcast in accordance with the set of link loss detection broadcast parameters; wherein the link loss detection broadcast parameters comprise: T_{sBCH} = a link loss detection broadcast interval; K = a number of symbols in the Physical Downlink Control

Channel (PDCCH); N = a maximum number of symbols of the link loss detection broadcast; and M = a link loss detection threshold.

Example 123 may include the apparatus of example 122, or any other example herein, wherein the link loss detection broadcast is allocated to wireless resources after or before the
5 PDCCH.

Example 124 may include the apparatus of example 122 or 123, or any other example herein, wherein the wireless resources allocated to the link loss detection broadcast is configured through system information.

Example 125 may include the apparatus of any of examples 122 to 124, or any other example
10 herein, wherein the link loss detection broadcast has variable length, up to a maximum length provided to the UE in advance of receipt.

Example 126 may include the apparatus of any of examples 122 to 125, or any other example herein, wherein the link loss detection broadcast comprises a cell identification (cell ID) and sector index

15 Example 127 may include the apparatus of any of examples 122 to 126, or any other example herein, wherein directional transmissions comprise millimeter wave transmissions.

Example 128 may include the apparatus of any of examples 122 to 127, or any other example herein, wherein link loss detection broadcast parameters are sent via system information.

Example 129 may include the apparatus of any of examples 104 to 128, or any other example
20 herein, wherein the link loss detection broadcast comprises a shortened Broadcast CHannel (sBCH) or an enhanced Reference Signal (eRS) persistently allocated for every Transmit Time Interval (TTI) associated with the communications link.

Example 130 may include the apparatus of any of examples 104 to 111, or any other example
25 herein, wherein persistently allocated comprises being allocated to persistent time and frequency wireless resources.

Example 131 may include machine readable storage media having machine executable instructions that, when executed, cause one or more processors to perform an operation between a User Equipment (UE) and at least two wireless network cells comprising: maintaining a primary communications link with a first network cell; maintaining a
30 secondary communications link with a second network cell; and forming a persistent UpLink (UL) Scheduling Request message (pSR REQ Message (UL)) for transmission on the secondary communications link; wherein forming a persistent UL Scheduling Request message comprises: receiving a first offset value, $d_{\text{pSR-REQ}}$, the first offset value indicative of

an offset of symbols between a first symbol of the persistent UL Scheduling Request message sent on an Uplink and a last symbol that can be used for DownLink (DL)/UpLink (UL) allocation in a respective subframe; receiving a second offset value, $d_{\text{pSR-RSP}}$, the second offset value indicative of an offset of symbols between the first symbol of the persistent UL Scheduling Request message and a first symbol of the persistent UL Scheduling Response message; receiving a cycle time of the persistent UL Scheduling Request message, T_{pSR} , in terms of slots or subframes; and forming the persistent UL Scheduling Request message dependent upon the received first offset value, second offset value and cycle time.

Example 132 may include the machine readable storage media of example 131, or any other example herein, further comprising receiving a persistent UL Scheduling Response message (pSR Resp Message (UL)) on the secondary communications link dependent upon the received first offset value, second offset value and cycle time.

Example 133 may include the machine readable storage media of example 131 or 132, or any other example herein, wherein forming the persistent UL Scheduling Request message dependent upon the received first offset value, second offset value and cycle time comprises using the first offset to determine a position in a subframe to transmit the persistent UL Scheduling Request message, the position being relative to the end of the subframe in which the persistent UL Scheduling Request message is to be sent.

Example 134 may include the machine readable storage media of any of examples 131 to 133, or any other example herein, wherein forming the persistent UL Scheduling Response message dependent upon the received first offset value, second offset value and cycle time comprises using the first offset to determine a position in a subframe to transmit the persistent UL Scheduling Request message, the position being relative to the end of the subframe in which the persistent UL Scheduling Request message is to be sent, and using the second offset value to determine a second position in a subframe to transmit the persistent UL Scheduling Response message, the second position being relative to the first position.

Example 135 may include the machine readable storage media of any of examples 131 to 134, or any other example herein, wherein the position in a subframe to transmit the persistent UL Scheduling Request message is located a symbol distance $d_{\text{pSR-REQ}}$ away from the end of the subframe, or the first symbol of the common control and reference signals (Primary Synchronization Signal (PSS)/Secondary Synchronization Signal (SSS)/Broadcast Channel (BCH)/Sector Level Sweep (SLS)).

Example 136 may include the machine readable storage media of any of examples 131 to 135, or any other example herein, wherein the second position in a subframe to transmit the persistent UL Scheduling Response message is located a symbol distance $d_{\text{pSR-RSP}}$ away from the start of the UL Scheduling Request message.

- 5 Example 137 may include the machine readable storage media of any of examples 131 to 136, or any other example herein, further comprising transmitting the persistent UL Scheduling Request (pSR) message on the secondary communications link.

Example 138 may include the machine readable storage media of any of examples 131 to 137, or any other example herein, further comprising transmitting the persistent UL

- 10 Scheduling Response message on the secondary communications link.

Example 139 may include a method in a UE comprising: maintaining a primary communications link with a first network cell; maintaining a secondary communications link with a second network cell; and forming a persistent UpLink (UL) Scheduling Request message (pSR REQ Message (UL)) for transmission on the secondary communications link;

- 15 wherein forming a persistent UL Scheduling Request message comprises: receiving a first offset value, $d_{\text{pSR-REQ}}$, the first offset value indicative of an offset of symbols between a first symbol of the persistent UL Scheduling Request message sent on an Uplink and a last symbol that can be used for DownLink (DL)/UpLink (UL) allocation in a respective subframe; receiving a second offset value, $d_{\text{pSR-RSP}}$, the second offset value indicative of an offset of
20 symbols between the first symbol of the persistent UL Scheduling Request message and a first symbol of the persistent UL Scheduling Response message; receiving a cycle time of the persistent UL Scheduling Request message, T_{pSR} , in terms of slots or subframes; and forming the persistent UL Scheduling Request message dependent upon the received first offset value, second offset value and cycle time.

- 25 Example 140 may include the method of example 139, or any other example herein, further comprising receiving a persistent UL Scheduling Response message (pSR Resp Message (UL)) on the secondary communications link dependent upon the received first offset value, second offset value and cycle time.

- Example 141 may include the method of example 139 or 140, or any other example herein,
30 wherein forming the persistent UL Scheduling Request message dependent upon the received first offset value, second offset value and cycle time comprises using the first offset to determine a position in a subframe to transmit the persistent UL Scheduling Request

message, the position being relative to the end of the subframe in which the persistent UL Scheduling Request message is to be sent.

Example 142 may include the method of any of examples 139 to 141, or any other example herein, wherein forming the persistent UL Scheduling Response message dependent upon the received first offset value, second offset value and cycle time comprises using the first offset to determine a position in a subframe to transmit the persistent UL Scheduling Request message, the position being relative to the end of the subframe in which the persistent UL Scheduling Request message is to be sent, and using the second offset value to determine a second position in a subframe to transmit the persistent UL Scheduling Response message, the second position being relative to the first position.

Example 143 may include the method of any of examples 139 to 142, or any other example herein, wherein the position in a subframe to transmit the persistent UL Scheduling Request message is located a symbol distance $d_{\text{pSR-REQ}}$ away from the end of the subframe, or the first symbol of the common control and reference signals (Primary Synchronization Signal (PSS)/Secondary Synchronization Signal (SSS)/Broadcast Channel (BCH)/Sector Level Sweep (SLS)).

Example 144 may include the method of any of examples 139 to 144, or any other example herein, wherein the second position in a subframe to transmit the persistent UL Scheduling Response message is located a symbol distance $d_{\text{pSR-RSP}}$ away from the start of the UL Scheduling Request message.

Example 145 may include the method of any of examples 139 to 145, or any other example herein, further comprising transmitting the persistent UL Scheduling Request (pSR) message on the secondary communications link.

Example 146 may include the method of any of examples 139 to 146, or any other example herein, further comprising transmitting the persistent UL Scheduling Response message on the secondary communications link.

Example 147 may include an apparatus of a User Equipment (UE) operable to communicate with an evolved Node-B (eNB) in a wireless network, comprising: one or more processors to: maintain a primary communications link with a first network cell; maintain a secondary communications link with a second network cell; and form a persistent UpLink (UL) Scheduling Request message (pSR REQ Message (UL)) for transmission on the secondary communications link; wherein, to form a persistent UL Scheduling Request message, the one

or more processors are to: receive a first offset value, $d_{\text{pSR-REQ}}$, the first offset value indicative of an offset of symbols between a first symbol of the persistent UL Scheduling Request message sent on an Uplink and a last symbol that can be used for DownLink (DL)/UpLink (UL) allocation in a respective subframe; receive a second offset value, $d_{\text{pSR-RSP}}$, the second
5 offset value indicative of an offset of symbols between the first symbol of the persistent UL Scheduling Request message and a first symbol of the persistent UL Scheduling Response message; receive a cycle time of the persistent UL Scheduling Request message, T_{pSR} , in terms of slots or subframes; and form the persistent UL Scheduling Request message dependent upon the received first offset value, second offset value and cycle time.

10 Example 148 may include the apparatus of example 147, or any other example herein, wherein the one or more processors are further to receive a persistent UL Scheduling Response message (pSR Resp Message (UL)) on the secondary communications link dependent upon the received first offset value, second offset value and cycle time.

Example 149 may include the apparatus of example 147 or 148, or any other example herein,
15 wherein the one or more processors are further to form the persistent UL Scheduling Request message dependent upon the received first offset value, second offset value and cycle time comprises using the first offset to determine a position in a subframe to transmit the persistent UL Scheduling Request message, the position being relative to the end of the subframe in which the persistent UL Scheduling Request message is to be sent.

20 Example 150 may include the apparatus of any of examples 147 to 149, or any other example herein, wherein the one or more processors are further to form the persistent UL Scheduling Response message dependent upon the received first offset value, second offset value and cycle time comprises using the first offset to determine a position in a subframe to transmit the persistent UL Scheduling Request message, the position being relative to the end of the
25 subframe in which the persistent UL Scheduling Request message is to be sent, and using the second offset value to determine a second position in a subframe to transmit the persistent UL Scheduling Response message, the second position being relative to the first position.

Example 151 may include the apparatus of any of examples 147 to 150, or any other example herein, wherein the position in a subframe to transmit the persistent UL Scheduling Request
30 message is located a symbol distance $d_{\text{pSR-REQ}}$ away from the end of the subframe, or the first symbol of the common control and reference signals (Primary Synchronization Signal (PSS)/Secondary Synchronization Signal (SSS)/Broadcast Channel (BCH)/Sector Level Sweep (SLS)).

Example 152 may include the apparatus of any of examples 147 to 151, or any other example herein, wherein the second position in a subframe to transmit the persistent UL Scheduling Response message is located a symbol distance $d_{\text{pSR-RSP}}$ away from the start of the UL Scheduling Request message.

- 5 Example 153 may include the apparatus of any of examples 147 to 152, or any other example herein, wherein the one or more processors are further to transmit the persistent UL Scheduling Request (pSR) message on the secondary communications link.

Example 154 may include the apparatus of any of examples 147 to 153, or any other example herein, wherein the one or more processors are further to transmit the persistent UL

- 10 Scheduling Response message on the secondary communications link.

Example 155 may include machine readable storage media having machine executable instructions that, when executed, cause one or more processors to perform an operation between a User Equipment (UE) and at least two wireless network cells comprising:

- 15 maintaining at least one primary communications link between the UE and a first network cell and using the at least one primary communications link to send and receive data between the UE and the wireless network; maintaining at least one secondary communications link between the UE and a second network cell and using the at least one secondary communications link to send and receive control messages (e.g. scheduling request) between the UE and the wireless network; detecting a loss of a primary communications link; and
- 20 carrying out a fast cell switching (FCS) procedure at the UE to switch communications from the lost at least one primary communications link to use a one of the at least one secondary communications link.

- Example 156 may include the machine readable storage media of example 155, or any other example herein, wherein the FCS procedure comprises: selecting an appropriate one of the at
- 25 least one secondary communications link transmitting a FCS switch request control message over the selected secondary communications link to an Evolved Node-B (eNB) providing the secondary communications link; receiving an FCS switch response control message from the eNB providing the secondary communications link.

- Example 157 may include the machine readable storage media of example 155 or 156, or any
- 30 other example herein, wherein the FCS procedure further comprises: setting the eNB providing the secondary communications link as a new primary eNB providing a new primary communications link; and sending and receiving all data between the UE and the wireless network over the new primary communications link.

Example 158 may include the machine readable storage media of any of examples 155 to 157, or any other example herein, wherein transmitting a FCS switch request message over the selected secondary communications link to an eNB providing the secondary communications link comprises transmitting the FCS switch request in a persistent

5 Scheduling Request message (pSR-REQ).

Example 159 may include the machine readable storage media of any of examples 155 to 158, or any other example herein, wherein receiving an FCS switch response message from the eNB providing the secondary communications link comprises receiving the FCS switch response in a persistent Scheduling Response message (pSR-RSP).

10 Example 160 may include the machine readable storage media of any of examples 155 to 159, or any other example herein, wherein the operation of examples 155 to 159 occurs in a UE.

Example 161 may include a method in a User Equipment (UE) comprising: maintaining at least one primary communications link between the UE and a first network cell and using the
15 at least one primary communications link to send and receive data between the UE and the wireless network; maintaining at least one secondary communications link between the UE and a second network cell and using the at least one secondary communications link to send and receive control messages (e.g. scheduling request) between the UE and the wireless network; detecting a loss of a primary communications link; and carrying out a fast cell
20 switching (FCS) procedure at the UE to switch communications from the lost at least one primary communications link to use a one of the at least one secondary communications link.

Example 162 may include the method of example 161, or any other example herein, wherein the FCS procedure comprises: selecting an appropriate one of the at least one secondary communications link transmitting a FCS switch request control message over the selected
25 secondary communications link to an evolved Nobe-B (eNB) providing the secondary communications link; receiving an FCS switch response control message from the eNB providing the secondary communications link.

Example 163 may include the method of example 161 or 162, or any other example herein, wherein the FCS procedure further comprises: setting the eNB providing the secondary
30 communications link as a new primary eNB providing a new primary communications link; and sending and receiving all data between the UE and the wireless network over the new primary communications link.

Example 164 may include the method of any of examples 161 to 163, or any other example herein, wherein transmitting a FCS switch request message over the selected secondary communications link to an eNB providing the secondary communications link comprises transmitting the FCS switch request in a persistent Scheduling Request message (pSR-REQ).

5 Example 165 may include the method of any of examples 161 to 164, or any other example herein, wherein receiving an FCS switch response message from the eNB providing the secondary communications link comprises receiving the FCS switch response in a persistent Scheduling Response message (pSR-RSP).

10 Example 166 may include an apparatus for a User Equipment (UE) comprising: one or more processors to: maintain at least one primary communications link between the UE and a first network cell and using the at least one primary communications link to send and receive data between the UE and the wireless network; maintain at least one secondary communications link between the UE and a second network cell and using the at least one secondary communications link to send and receive control messages (e.g. scheduling request) between
15 the UE and the wireless network; detect a loss of a primary communications link; and carry out a fast cell switching (FCS) procedure at the UE to switch communications from the lost at least one primary communications link to use a one of the at least one secondary communications link.

20 Example 167 may include the apparatus of example 166, wherein the one or more processors are further to: select an appropriate one of the at least one secondary communications link transmit a FCS switch request control message over the selected secondary communications link to an evolved Node-B (eNB) providing the secondary communications link; receive an FCS switch response control message from the eNB providing the secondary communications link.

25 Example 168 may include the apparatus of example 166 or 167, or any other example herein, wherein the one or more processors are further to: set the eNB providing the secondary communications link as a new primary eNB providing a new primary communications link; and send and receiving all data between the UE and the wireless network over the new primary communications link.

30 Example 169 may include the apparatus of any of examples 166 to 168, or any other example herein, wherein the one or more processors are further to transmit a FCS switch request to the eNB in a persistent Scheduling Request message (pSR-REQ).

Example 170 may include the apparatus of any of examples 166 to 169, or any other example herein, wherein the one or more processors are further to receive an FCS switch response message from the eNB in a persistent Scheduling Response message (pSR-RSP).

Example 171 may include machine readable storage media having machine executable

5 instructions that, when executed, cause one or more processors to perform an operation between a User Equipment (UE) and at least two wireless network cells comprising:
maintaining at least one primary communications link between the UE and a first Evolved Node-B (eNB) of a first network cell and using the at least one primary communications link to send and receive data between the UE and the wireless network; maintaining at least one
10 secondary communications link between the UE and a second eNB of a second network cell and using the at least one secondary communications link to send and receive persistent scheduling messages between the UE and the wireless network; receiving a fast cell switching request message from the UE at the second eNB providing the secondary network cell when a one of the at least one primary communications link to the UE is lost;
15 transmitting, from the second eNB providing the secondary network cell, a fast cell switching response message to the UE over the secondary communications link; transmitting, from the second eNB to the anchor eNB providing communications between the UE and a core network serving the wireless network, a fast cell switching notification message to control the first eNB to forward all communications for the UE to the second eNB for onward
20 transmission to the UE by the second eNB.

Example 172 may include the machine readable storage media of example 171, or any other example herein, further comprising initiating a sector scanning procedure at the second eNB to select a most appropriate sector of the second eNB for use to communicate with the UE.

Example 173 may include the machine readable storage media of any of examples 171 or
25 172, or any other example herein, wherein selecting most appropriate sector of the second eNB for use to communicate with the UE comprising selecting a sector having a selection parameter exceeding a predetermined threshold.

Example 174 may include the machine readable storage media of any of examples 171 to 173, or any other example herein, wherein receiving a fast cell switching request message
30 from the UE at the second eNB comprises receiving the FCS switch request in a persistent Scheduling Request message (pSR-REQ).

Example 175 may include the machine readable storage media of any of examples 171 to 174, or any other example herein, wherein transmitting FCS switch response message from

the second eNB comprises transmitting the FCS switch response in a persistent Scheduling Response message (pSR-RSP).

Example 176 may include the machine readable storage media of any of examples 171 to 175, or any other example herein, further comprising detecting a loss of a primary
5 communications link according to any of examples 81 to 84 or 94 to 98.

Example 177 may include the machine readable storage media of any of examples 171 to 176, or any other example herein, wherein the operation occurs in an eNB.

Example 178 may include a method in an Evolved Node-B (eNB) comprising: maintaining at least one primary communications link between a User Equipment (UE) and a first eNB of a
10 first network cell and using the at least one primary communications link to send and receive data between the UE and the wireless network; maintaining at least one secondary communications link between the UE and a second eNB of a second network cell and using the at least one secondary communications link to send and receive persistent scheduling messages between the UE and the wireless network; receiving a fast cell switching request
15 message from the UE at the second eNB providing the secondary network cell when a one of the at least one primary communications link to the UE is lost; transmitting, from the second eNB providing the secondary network cell, a fast cell switching response message to the UE over the secondary communications link; transmitting, from the second eNB to the anchor eNB providing communications between the UE and a core network serving the wireless
20 network, a fast cell switching notification message to control the first eNB to forward all communications for the UE to the second eNB for onward transmission to the UE by the second eNB.

Example 179 may include the method of example 178, or any other example herein, further comprising initiating a sector scanning procedure at the second eNB to select a most
25 appropriate sector of the second eNB for use to communicate with the UE.

Example 180 may include the method of any of examples 178 or 179, or any other example herein, wherein selecting most appropriate sector of the second eNB for use to communicate with the UE comprising selecting a sector having a selection parameter exceeding a predetermined threshold.

30 Example 181 may include the method of any of examples 178 to 180, or any other example herein, wherein receiving a fast cell switching request message from the UE at the second eNB comprises receiving the FCS switch request in a persistent Scheduling Request message (pSR-REQ).

Example 182 may include the method of any of examples 178 to 181, or any other example herein, wherein transmitting FCS switch response message from the second eNB comprises transmitting the FCS switch response in a persistent Scheduling Response message (pSR-RSP).

- 5 Example 183 may include the method of any of examples 178 to 182, or any other example herein, further comprising detecting a loss of a primary communications link according to any of examples 81 to 84 or 94 to 98.

Example 184 may include an apparatus for an Evolved Node-B (eNB) comprising: one or more processors to: maintain at least one primary communications link between a User
10 Equipment (UE) and a first eNB of a first network cell and using the at least one primary communications link to send and receive data between the UE and the wireless network; maintain at least one secondary communications link between the UE and a second eNB of a second network cell and using the at least one secondary communications link to send and receive persistent scheduling messages between the UE and the wireless network; receive a
15 fast cell switching request message from the UE at the second eNB providing the secondary network cell when a one of the at least one primary communications link to the UE is lost; transmit, from the second eNB providing the secondary network cell, a fast cell switching response message to the UE over the secondary communications link; transmit, from the second eNB to the anchor eNB providing communications between the UE and a core
20 network serving the wireless network, a fast cell switching notification message to control the first eNB to forward all communications for the UE to the second eNB for onward transmission to the UE by the second eNB.

Example 185 may include the apparatus of example 184, or any other example herein, wherein the one or more processors are further to initiate a sector scanning procedure at the
25 second eNB to select a most appropriate sector of the second eNB for use to communicate with the UE.

Example 186 may include the apparatus of any of examples 184 or 185, or any other example herein, wherein the one or more processors are further to select a most appropriate sector of the second eNB for use to communicate with the UE dependent upon a selection parameter
30 exceeding a predetermined threshold.

Example 187 may include the apparatus of any of examples 184 to 186, or any other example herein, wherein the one or more processors are further to receive a fast cell switching request

message from the UE at the second eNB comprises in a persistent Scheduling Request message (pSR-REQ).

Example 188 may include the apparatus of any of examples 184 to 187, or any other example herein, wherein the one or more processors are further to transmit the FCS switch response in
5 a persistent Scheduling Response message (pSR-RSP).

Example 189 may include the apparatus of any of examples 184 to 188, or any other example herein, wherein the one or more processors are further to detect a loss of a primary communications link according to any of examples 81 to 84 or 94 to 98.

Example 190 may include an apparatus comprising means for carrying any of method
10 examples 21 to 28, 52 to 62, 70 to 76, 81 to 84, 94 to 98, 113 to 121, 139 to 146, 161 to 165, and 178 to 183. Unless otherwise explicitly stated as incompatible, or the physics or otherwise of the embodiments, example or claims prevent such a combination, the features of the foregoing embodiments and examples, and of the following claims may be integrated together in any suitable arrangement, especially ones where there is a beneficial effect in
15 doing so. This is not limited to only any specified benefit, and instead may arise from an “ex post facto” benefit. This is to say that the combination of features is not limited by the described forms, particularly the form (e.g. numbering) of the example(s), embodiment(s), or dependency of the claim(s). Moreover, this also applies to the phrase “in one embodiment”, “according to an embodiment” and the like, which are merely a stylistic form of wording and
20 are not to be construed as limiting the following features to a separate embodiment to all other instances of the same or similar wording. This is to say, a reference to ‘an’, ‘one’ or ‘some’ embodiment(s) may be a reference to any one or more, and/or all embodiments, or combination(s) thereof, disclosed. Also, similarly, the reference to “the” embodiment may not be limited to the immediately preceding embodiment. An abstract is provided that will
25 allow the reader to ascertain the nature and gist of the technical disclosure. The abstract is submitted with the understanding that it will not be used to limit the scope or meaning of the claims. The following claims are hereby incorporated into the detailed description, with each claim standing on its own as a separate embodiment.

CLAIMS

We claim:

1. An apparatus of a User Equipment (UE) operable to communicate with an Evolved
5 Node-B (eNB) on a wireless network, comprising:
one or more processors to:
maintain a plurality of radio access network communications links between
the UE and at least two eNBs of a radio access network of the wireless network,
wherein at least a first eNB is an anchor eNB and wherein at least a second eNB is a
10 booster eNB, said plurality of radio access network communications links between the
UE and a radio access network of the wireless network comprising at least one
primary communications link and at least one secondary communications link; and
switch between actively using the at least one primary communications link
for sending and receiving data of the UE to actively using the at least one secondary
15 communications link for sending and receiving data of the UE when the at least one
primary communications link is determined to be lost;
wherein the anchor eNB is operable to provide both communications between the UE
and a core network serving the wireless network, and communications between the UE and a
radio access network providing the wireless network; and
20 wherein the booster eNB is operable to provide communications between the UE and
the radio access network providing the wireless network, and is operable to communicate
with the core network only via the anchor eNB.
2. The apparatus of claim 1, wherein the anchor eNB provides both user-plane and
25 control-plane communications between the UE and the core network.
3. The apparatus of claim 1, wherein the booster eNB provides both user-plane and
control-plane communications between the UE and the anchor eNB.
- 30 4. The apparatus of claim 1, wherein the booster eNB communicates with the anchor
eNB over an eNB to eNB communications link interface, optionally an X2 interface.

5. The apparatus of claim 1, wherein the UE maintains at least two primary communications links, and wherein the one or more processors are further to split traffic to be sent between the at least two primary communications links.

5 6. The apparatus of claim 5, wherein to split traffic to be sent between the at least two primary communications links comprises providing at least two bearer links, wherein a bearer link is assigned to each primary communications link.

7. The apparatus of claim 1, wherein the one or more processors are further to:
10 provide a multi-connectivity convergence protocol (MCCP) stack entity, wherein the MCCP stack entity operates above individual radio access network protocol sub-stacks, and wherein the MCCP stack entity manages how the UE data traffic is routed over the primary and secondary communications links.

15 8. The apparatus of claim 1, wherein to operate above individual radio access network protocol sub-stacks comprises operating above the packet data convergence protocol (PDCP) stack entity of each wireless communications link(s) operating in the UE.

9. The apparatus of claim 1, wherein each wireless communications link(s) operating in
20 the UE comprises an independent user-plane and control-plane stack to provide operation independent from each other wireless communications link(s) operating in the UE.

10. The apparatus of claim 1, wherein the one or more processors are further to provide PDCP bearer splitting by the MCCP stack entity.

25

11. The apparatus of claim 7, wherein the MCCP stack entity comprises a user-plane portion, MCCP-u, and a control-plane portion, MCCP-c.

12. An apparatus of an Evolved Node-B (eNB) operable to communicate with a User
30 Equipment (UE) on a wireless network, comprising:
one or more processors to:

selectably operate the eNB in a first operational state that acts as an anchor eNB to at least one UE, wherein operating as the anchor eNB comprises providing communications between the at least one UE and a core network serving the wireless network; and

selectably operate the eNB in a second operational state that acts as a booster eNB to the at least one UE, wherein operating as the booster eNB comprises providing communications between the at least one UE and a radio access network of the wireless network;

wherein the one or more processors are further to:

select between the first and second operational states based upon information from the at least one UE.

13. The apparatus of claim 12, wherein the anchor eNB provides both user-plane and control-plane communications between the at least one UE and a core network.

14. The apparatus of claim 12, wherein the booster eNB provides both user-plane and control-plane communications between the at least one UE and the anchor eNB.

15. The apparatus of claim 12, wherein the booster eNB communicates with the anchor eNB over an eNB to eNB communications link interface, optionally an X2 interface.

16. The apparatus of claim 12, wherein the eNB provides at least two primary communications links with the at least one UE, and wherein the one or more processors are further to split traffic to be sent between the at least two primary communications links.

17. The apparatus of claim 12, wherein the one or more processors are further to: provide a multi-connectivity convergence protocol (MCCP) stack entity, wherein the MCCP stack entity operates above individual radio access network protocol sub-stacks, and wherein the MCCP stack entity manages how the at least one UE's data traffic is routed over the primary and secondary communications links.

18. An apparatus of a User Equipment (UE) operable to communicate with an Evolved Node-B (eNB) on a wireless network, comprising:

one or more processors to:

process communication signals received over a communications link; and
determine the communications link is lost by determining incorrect receipt of at least
one of a plurality of predetermined communications types over the communications link;

wherein the plurality of predetermined communications type comprises:

5 a Physical Downlink Control Channel (PDCCH);

a dedicated link loss detection broadcast located in a subframe portion to be received
after the PDCCH, having a set of link loss detection broadcast parameters; and

an enhanced Reference Signal (eRS) persistently allocated for every one for fixed
number of Transmit Time Intervals (TTIs) associated with the communications link; and

10 wherein incorrect receipt of the PDCCH, dedicated link loss detection broadcast or
enhanced Reference Signal comprises not receiving the PDCCH, dedicated link loss detection
broadcast or enhanced Reference Signal on given sector of an evolved Node-B (eNB) within
a predetermined time period.

15 19. The apparatus of claim 18, wherein the eRS is mapped onto a predetermined sector of
an eNB.

20. The apparatus of claim 18, wherein the eRS includes cell ID information.

20 21. The apparatus of claim 18, wherein time and frequency allocations of wireless
resources of the eRS are mapped to an eNB sector index.

22. A method in a User Equipment (UE) to detect a communications link loss,
comprising:

25 receiving a set of link loss detection broadcast parameters; and

using the set of link loss detection broadcast parameters to detect receipt of the link
loss detection broadcast;

wherein the operation further comprises:

determining a lost communications link associated with the link loss detection
30 broadcast when the link loss detection broadcast is not correctly received; or

determining the communications link associated with the link loss detection broadcast
is operational when the link loss detection broadcast is correctly received;

wherein the link loss detection broadcast parameters comprise:

T_{sBCH} = a link loss detection broadcast interval;

K = a number of symbols in the Physical Downlink Control Channel (PDCCH);

N = a maximum number of symbols of the link loss detection broadcast; and

M = a link loss detection threshold.

5

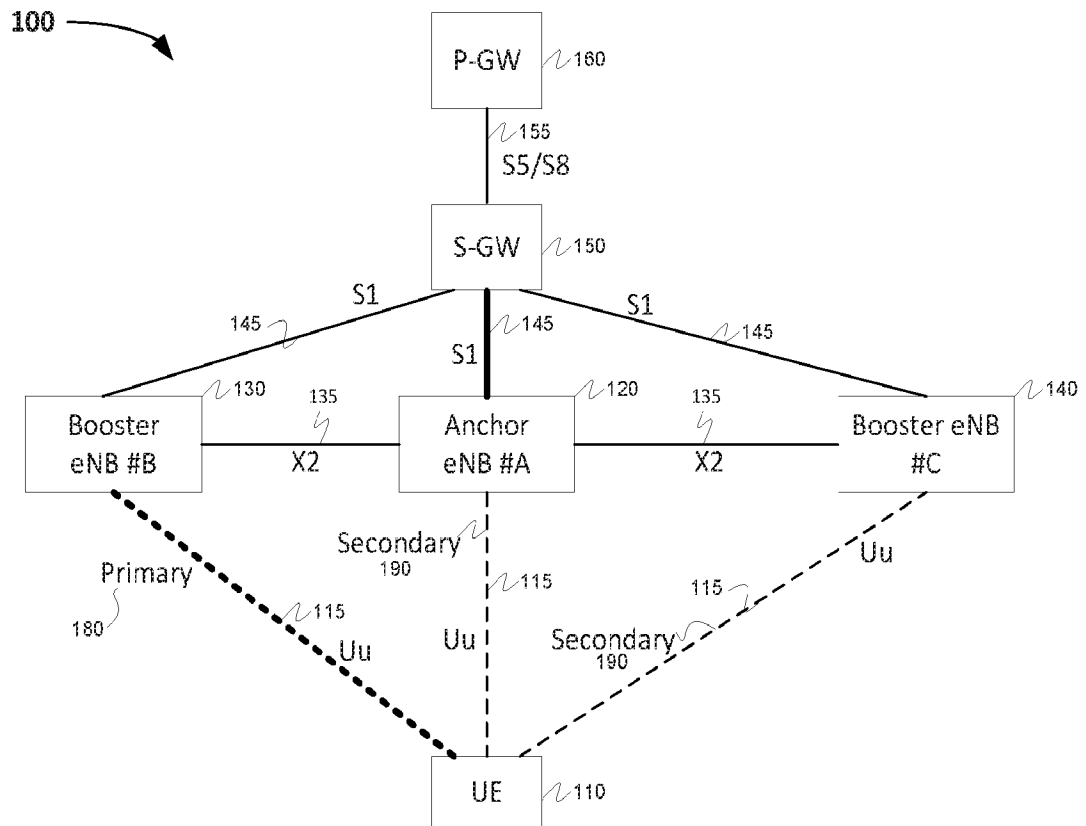
23. The method of claim 22, wherein the link loss detection broadcast is allocated to wireless resources after the PDCCH, or has variable length, up to a maximum length provided to the UE in advance of receipt.

10

24. The method of claim 22, wherein the wireless resources allocated to the link loss detection broadcast is configured through system information.

25. The method of claim 22, wherein the link loss detection broadcast comprises a cell identification (cell ID) and sector index.

15

**Fig. 1**

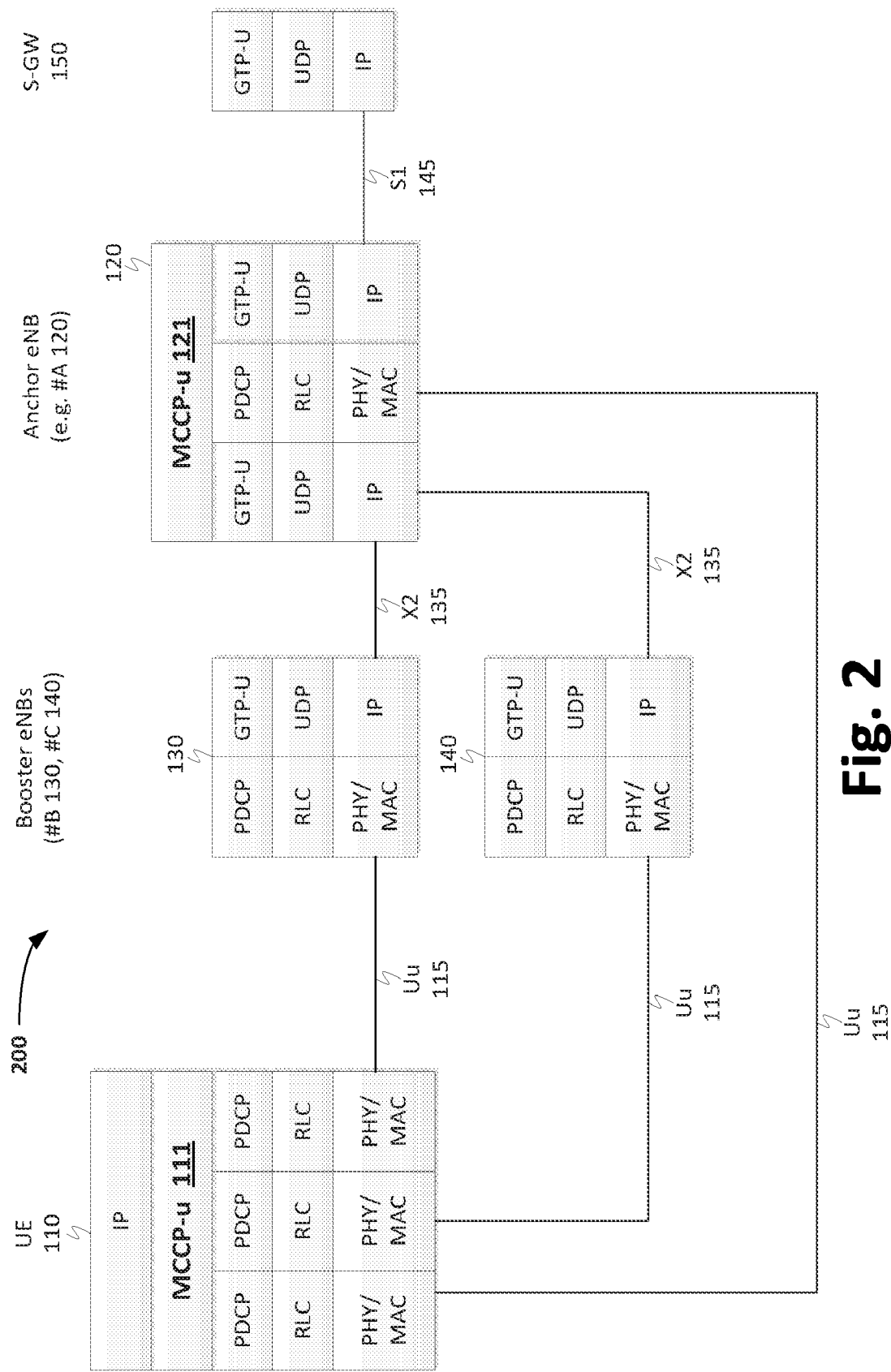
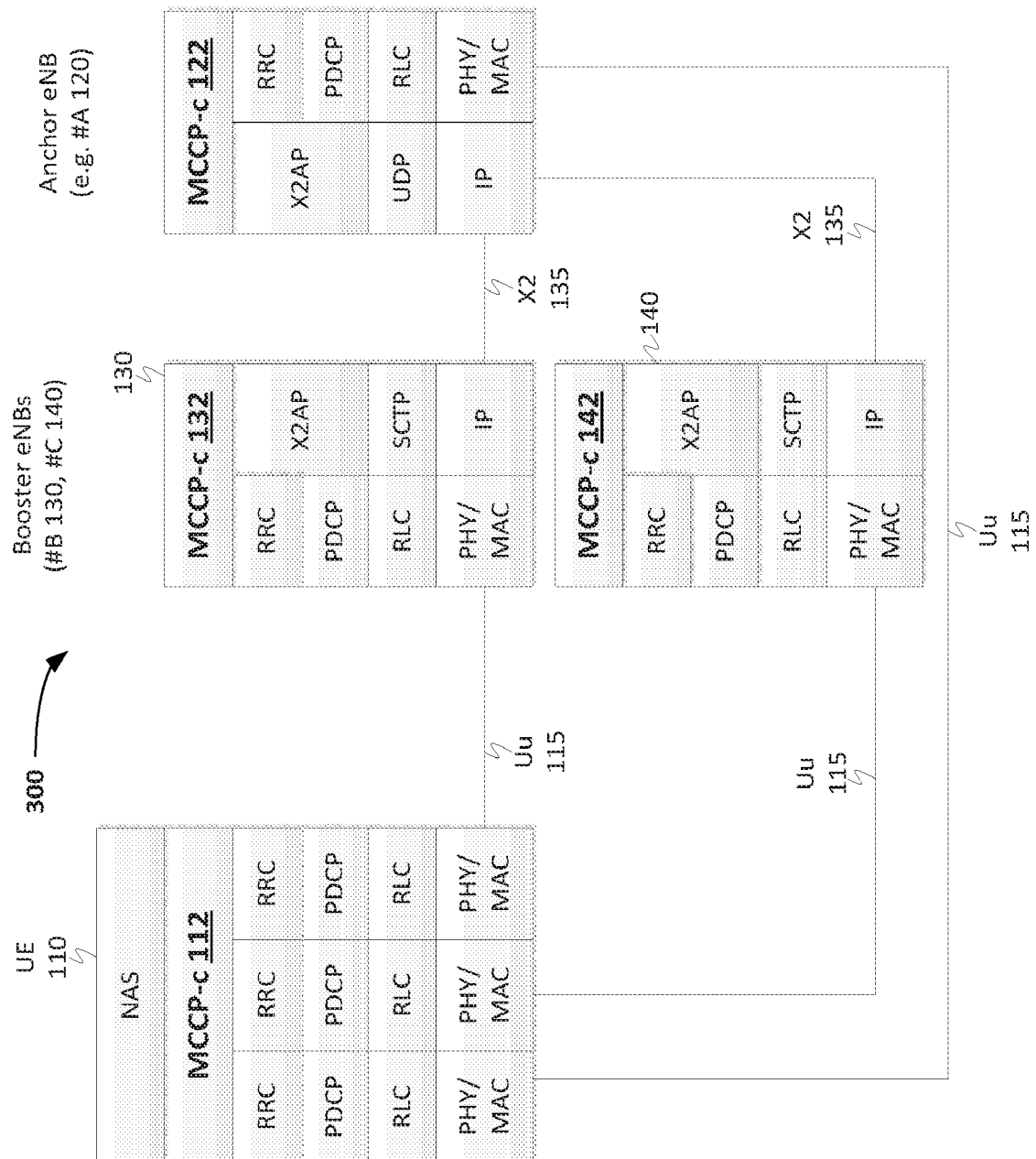


Fig. 2

**Fi**
bo
m

400 

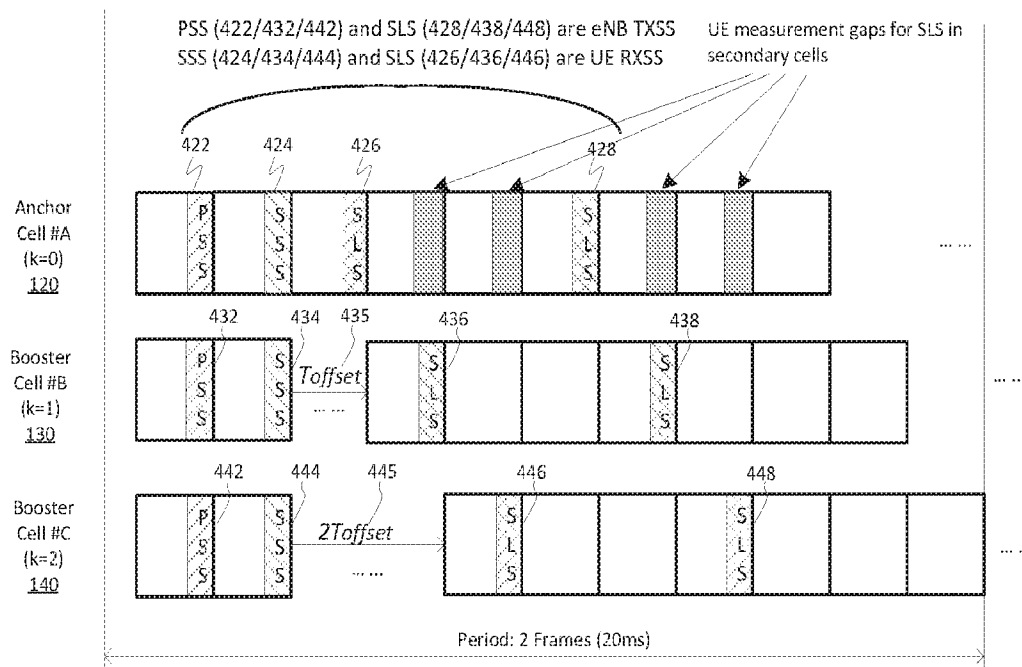


Fig. 4

500

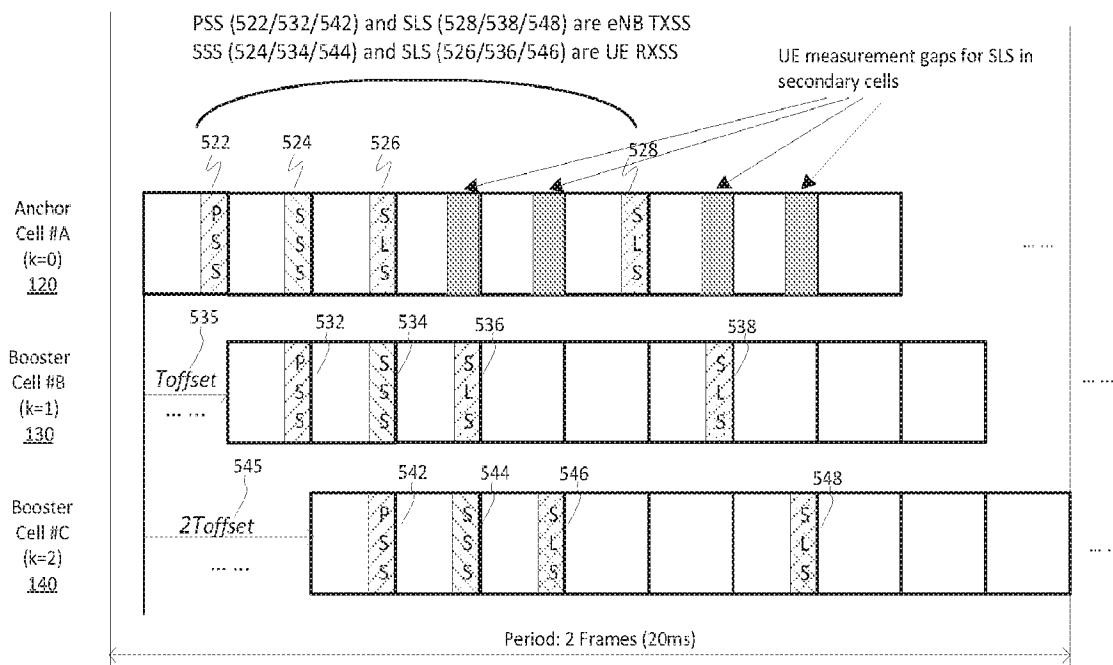


Fig. 5

5/10

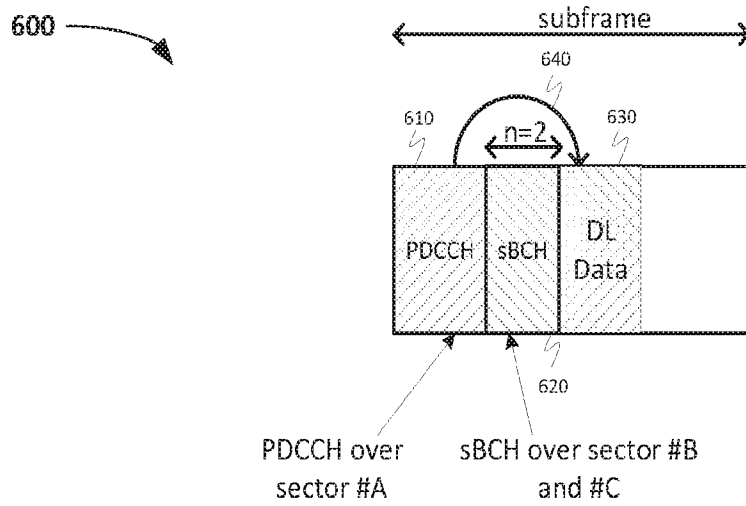


Fig. 6

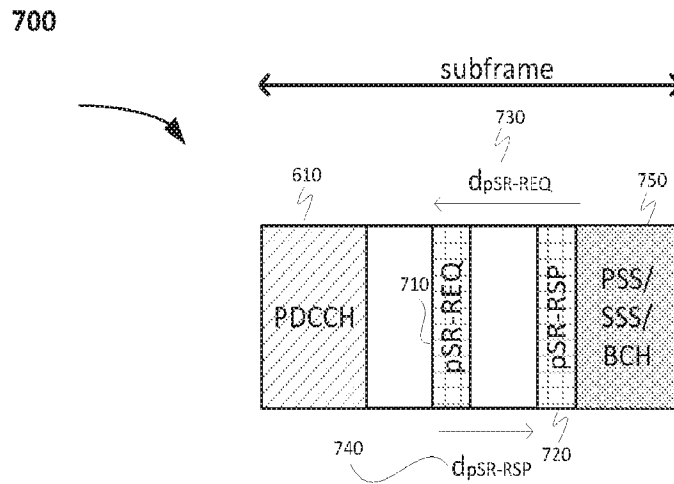


Fig. 7

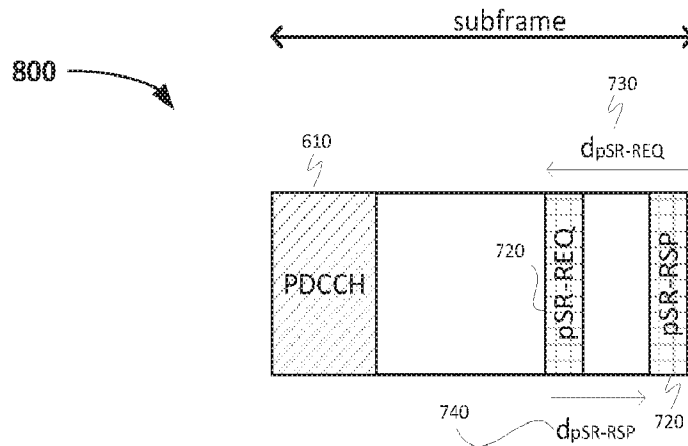
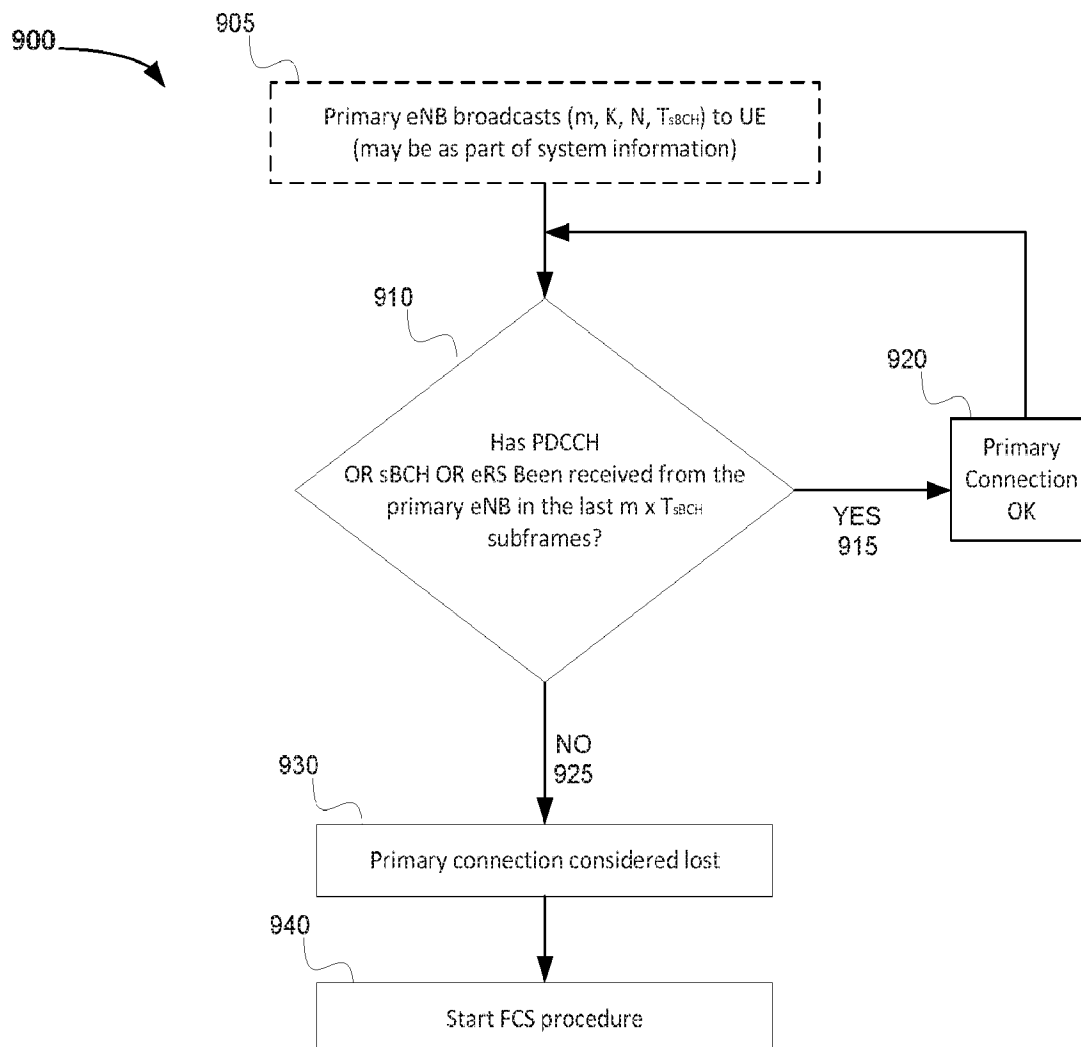


Fig. 8

**Fig. 9**

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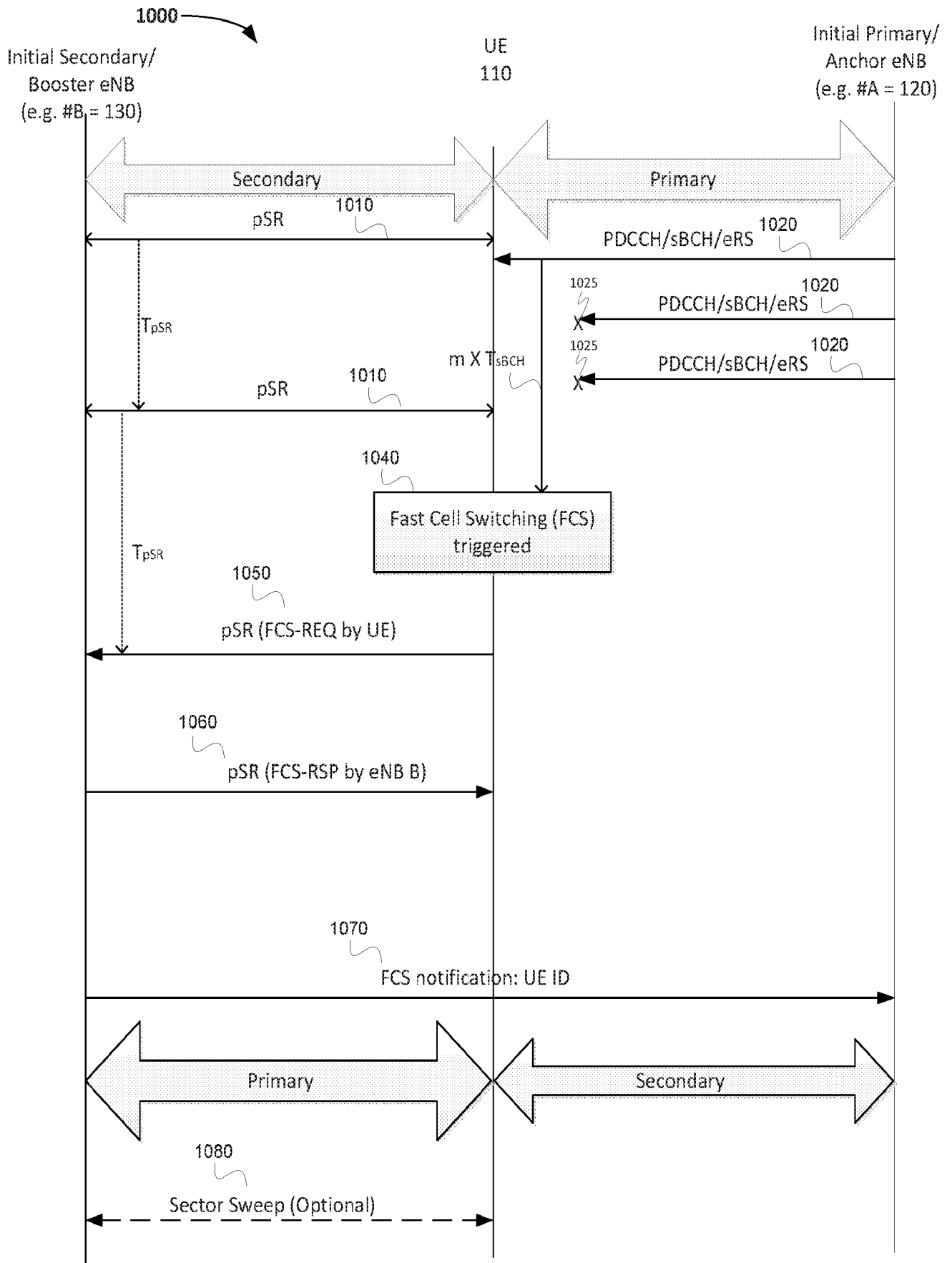
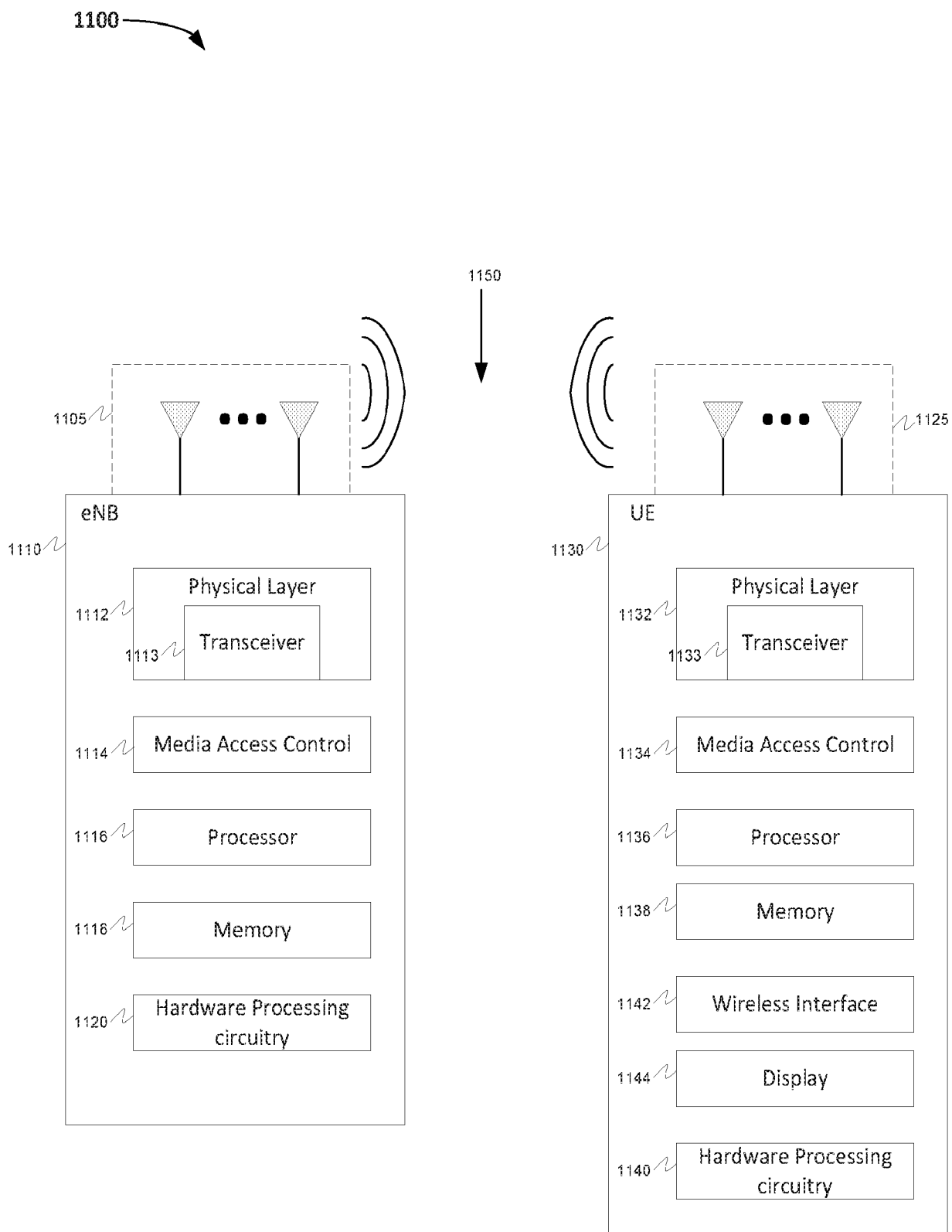


Fig. 10

**Fig. 11**

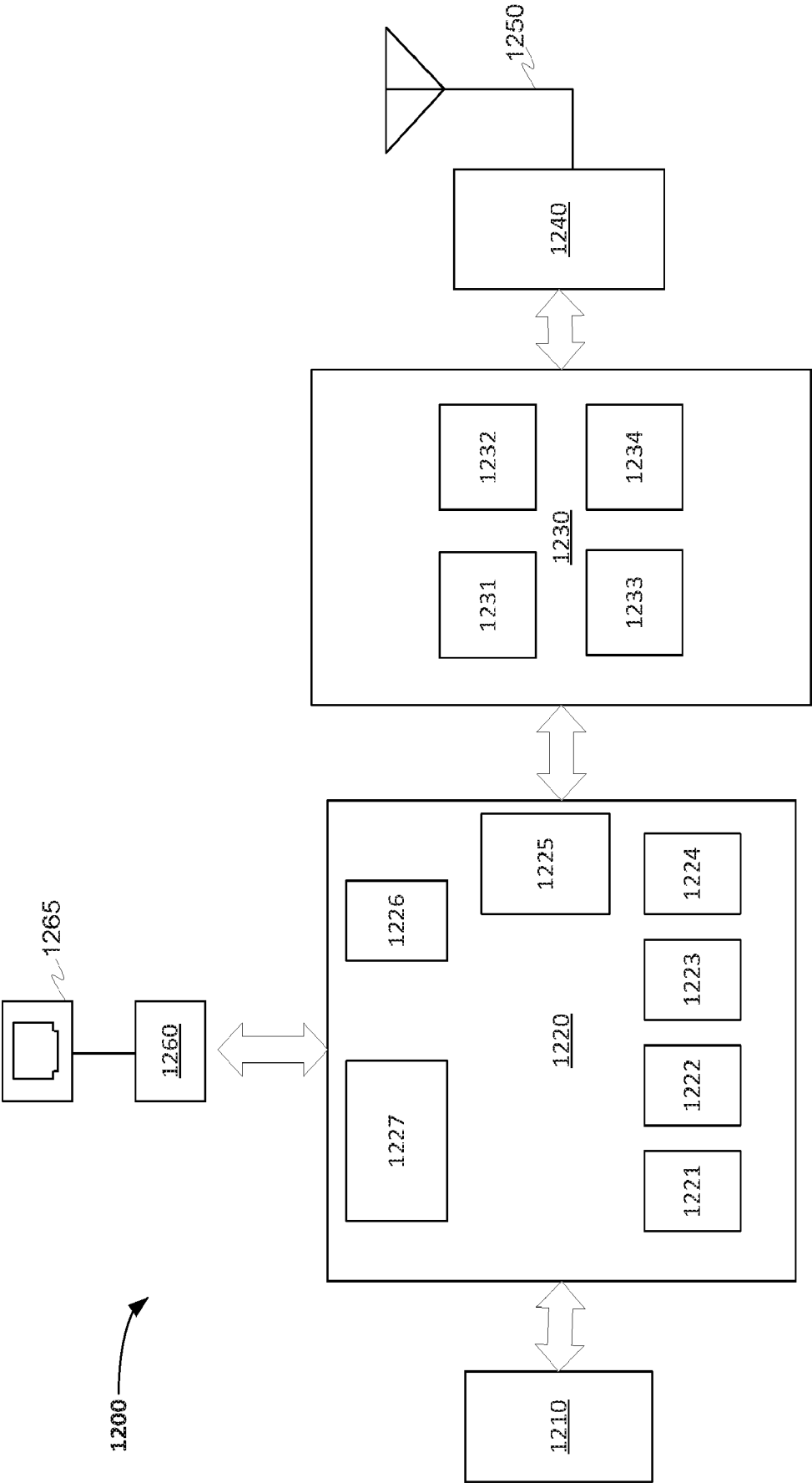
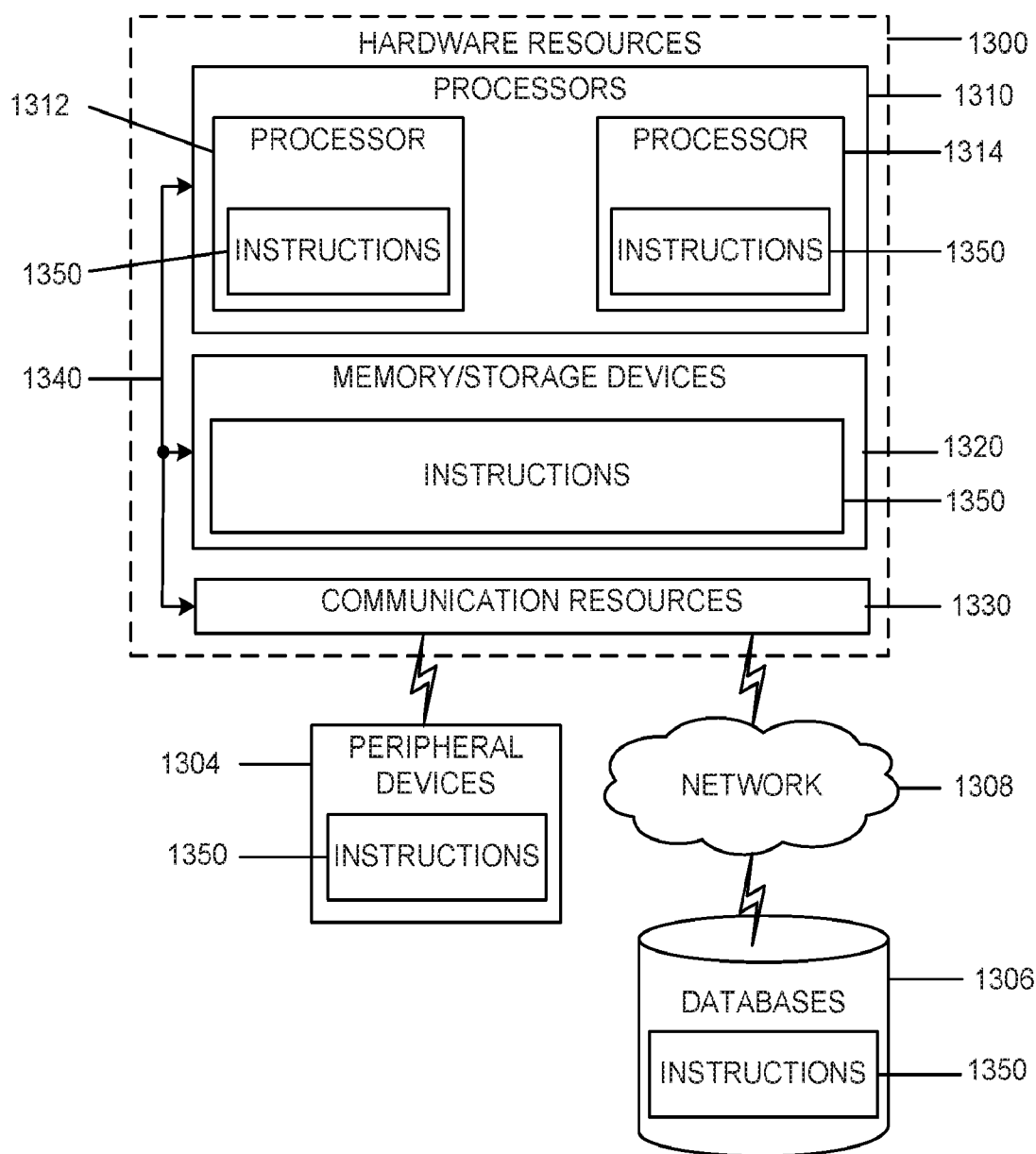


Fig. 12

10/10

**Fig. 13**

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2016/042134

A. CLASSIFICATION OF SUBJECT MATTER

INV. H04W36/36 H04W36/08 H04W36/30
ADD. H04W36/14 H04B7/02 H04W88/02 H04W88/08 H04B7/06
H04B7/08

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)

H04W H04B

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)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2015/045035 A1 (NIGAM ANSHUMAN [IN] ET AL) 12 February 2015 (2015-02-12) paragraph [0003] - paragraph [0011] -----	1-11
X	US 2015/358838 A1 (WEI NA [CN] ET AL) 10 December 2015 (2015-12-10)	1
Y	paragraph [0002] - paragraph [0005] paragraph [0070] - paragraph [0111] -----	2-10
X	US 2015/230134 A1 (CHIBA TSUNEHICO [JP] ET AL) 13 August 2015 (2015-08-13)	1
Y	paragraph [0038] - paragraph [0058] figures 1,2 ----- -/-	2-10



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

2 December 2016

Date of mailing of the international search report

07/02/2017

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
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Fax: (+31-70) 340-3016

Authorized officer

Gitzenis, Savvas

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2016/042134

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2013/310037 A1 (JI TINGFANG [US] ET AL) 21 November 2013 (2013-11-21)	1
Y	paragraph [0043] paragraph [0065] - paragraph [0100] pages 12, 13 -----	2-10
X	US 2014/321282 A1 (PRAGADA RAVIKUMAR V [US] ET AL) 30 October 2014 (2014-10-30)	1-6
Y	paragraph [0078] - paragraph [0140] paragraph [0180] - paragraph [0181] figures 7, 8, 15-17, 27 -----	7-11
Y	US 2016/037406 A1 (CENTONZA ANGELO [GB] ET AL) 4 February 2016 (2016-02-04)	2-11
A	paragraph [0012] - paragraph [0035] paragraph [0079] figures 3, 12 -----	1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2016/042134

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-11

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-11

A User Equipment (UE) operable to communicate with an Evolved Node-B (eNB) on a wireless network, that maintains a plurality of radio access network communications links between the UE and at least two eNBs of a radio access network of the wireless network, wherein at least a first eNB is an anchor eNB and wherein at least a second eNB is a booster eNB, said plurality of radio access network communications links between the UE and a radio access network of the wireless network comprising at least one primary communications link and at least one secondary communications link; and switches between actively using the at least one primary communications link for sending and receiving data of the UE to actively using the at least one secondary communications link for sending and receiving data of the UE when the at least one primary communications link is determined to be lost.

2. claims: 12-17

An eNB operable to communicate with a UE on a wireless network, that selectively operates the eNB in a first operational state that acts as an anchor eNB to at least one UE, wherein operating as the anchor eNB comprises providing communications between the at least one UE and a core network serving the wireless network, and in a second operational state that acts as a booster eNB to the at least one UE, wherein operating as the booster eNB comprises providing communications between the at least one UE and a radio access network of the wireless network; and selects between the first and second operational states based upon information from the at least one UE.

3. claims: 18-21

A UE operable to communicate with an eNB on a wireless network, that determines the communications link is lost by determining incorrect receipt of at least one of a plurality of predetermined communications types over the communications link, wherein the plurality of predetermined communications type comprises a Physical Downlink Control Channel (PDCCH), a dedicated link loss detection broadcast located in a subframe portion to be received after the PDCCH, having a set of link loss detection broadcast parameters and an enhanced Reference Signal (eRS) persistently allocated for every one for fixed number of Transmit Time Intervals (TTIs) associated with the communications link; and wherein incorrect receipt of the PDCCH, dedicated link loss detection broadcast or enhanced

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

Reference Signal comprises not receiving the PDCCH, dedicated link loss detection broadcast or enhanced Reference Signal on given sector of an eNB within a predetermined time period.

4. claims: 22-25

A method in a UE to detect a communications link loss comprising receiving a set of link loss detection broadcast parameters; and using the set of link loss detection broadcast parameters to detect receipt of the link loss detection broadcast; determining a lost communications link associated with the link loss detection broadcast when the link loss detection broadcast is not correctly received or that the communications link associated with the link loss detection broadcast is operational when the link loss detection broadcast is correctly received, wherein the link loss detection broadcast parameters comprise:

T sBCH = a link loss detection broadcast interval;

K = a number of symbols in the Physical Downlink Control Channel (PDCCH);

N = a maximum number of symbols of the link loss detection broadcast; and

M = a link loss detection threshold.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2016/042134

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		WO 2014163550 A1	09-10-2014