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SELECTIVE HANDOVER TO ENABLE MULTIPLE CONNECTIVITY OF A TERMINAL TOWARDS SEVERAL BASE STATIONS

1 Technical area/Keywords

Heterogeneous networks, Het Net, Pico, Soft cell, Handover, Handoff, LTE, Rel 12

2 Overview

With the proliferation of user friendly smart phones and tablets, the usage of high data rate services such as video streaming over the mobile network is becoming commonplace, greatly increasing the amount of traffic in mobile networks. Thus, there is a great urgency in the mobile network community to ensure that the capacity of mobile networks keeps up increasing with this ever-increasing user demand. The latest systems such as Long Term Evolution (LTE), especially when coupled with interference mitigation techniques, have spectral efficiencies very close to the theoretical Shannon limit. The continuous upgrading of current networks to support the latest technologies and densifying the number of base stations per unit area are two of the most widely used approaches to meet the increasing traffic demands.

Yet another approach that is gaining high attention is to use Heterogeneous Networks where the traditional pre-planned macro base stations (known as the *macro layer*) are complemented with several low-powered base stations that may be deployed in a relatively unplanned manner. The 3rd Generation Partnership Project (3GPP) has incorporated the concept of Heterogeneous Networks as one of the core items of study in the latest enhancements of LTE, such as LTE release 11. and several low-powered base stations for realizing heterogeneous networks such as *pico* base stations, *femto* base stations (also known as home base stations or HeNBs), relays, and RRHs (remote radio heads) have been defined.

The initial discussion for LTE release 12 has already started and one of the proposed items for study is the possibility of serving a User Equipment (UE) from more than one eNB simultaneously. The current legacy handover mechanisms of LTE have to be updated in order to support this.

3 Description

3.1 Technical Description

3.1.1 Overall E-UTRAN architecture

The Evolved UMTS Terrestrial Radio Access Network (E-UTRAN) consists of base stations called enhanced NodeBs (eNBs or eNodeBs), providing the E-UTRA user plane and control plane protocol terminations towards the UE. The eNBs are interconnected with each other by means of the X2 interface. The eNBs are also connected by means of the S1 interface to the EPC (Evolved Packet Core), more specifically to the MME (Mobility Management Entity) by means of the S1-MME interface and to the Serving Gateway (S-GW) by means of the S1-U interface. The S1 interface supports many-to-many relation between MMEs / S-GWs and eNBs. The E-UTRAN architecture is illustrated in Figure 1 below.

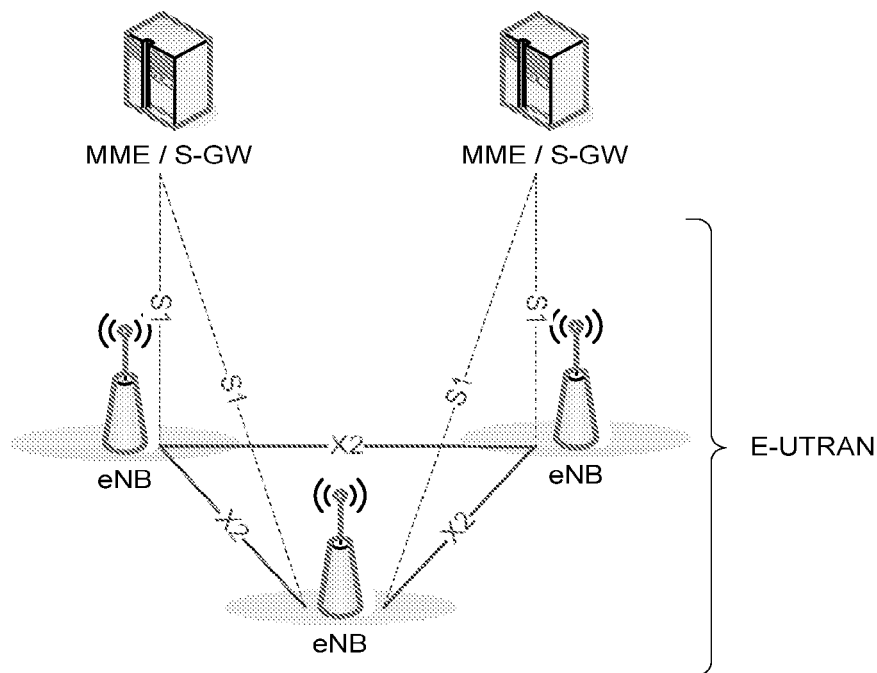


Figure 1: Overall E-UTRAN Architecture

The eNB hosts functionalities such as Radio Resource Management (RRM), radio bearer control, admission control, header compression of user plane data towards serving gateway, routing of user plane data towards the serving gateway. The MME is the control node that processes the signaling between the UE and the CN. The main functions of the MME are related to connection management and bearer management, which are handled via Non Access Stratum (NAS) protocols. The S-GW is the anchor point for UE mobility, and also comprises other functionalities such as temporary DL data buffering while the UE is being paged, packet routing and forwarding the right eNB, gathering of information for charging and lawful interception. The PDN Gateway (P-GW) is the node responsible for UE IP address allocation, as well as Quality of Service (QoS) enforcement (this is explained further in later sections). Figure 2 gives a summary of the functionalities of the different nodes, and the reader is referred to 3GPP TS 36.300 and the references therein for the details of the functionalities of the different nodes. In Figure 2, the yellow boxes depict the logical nodes, white boxes depict the functional entities of the control plane and blue boxes depict the radio protocol layers.

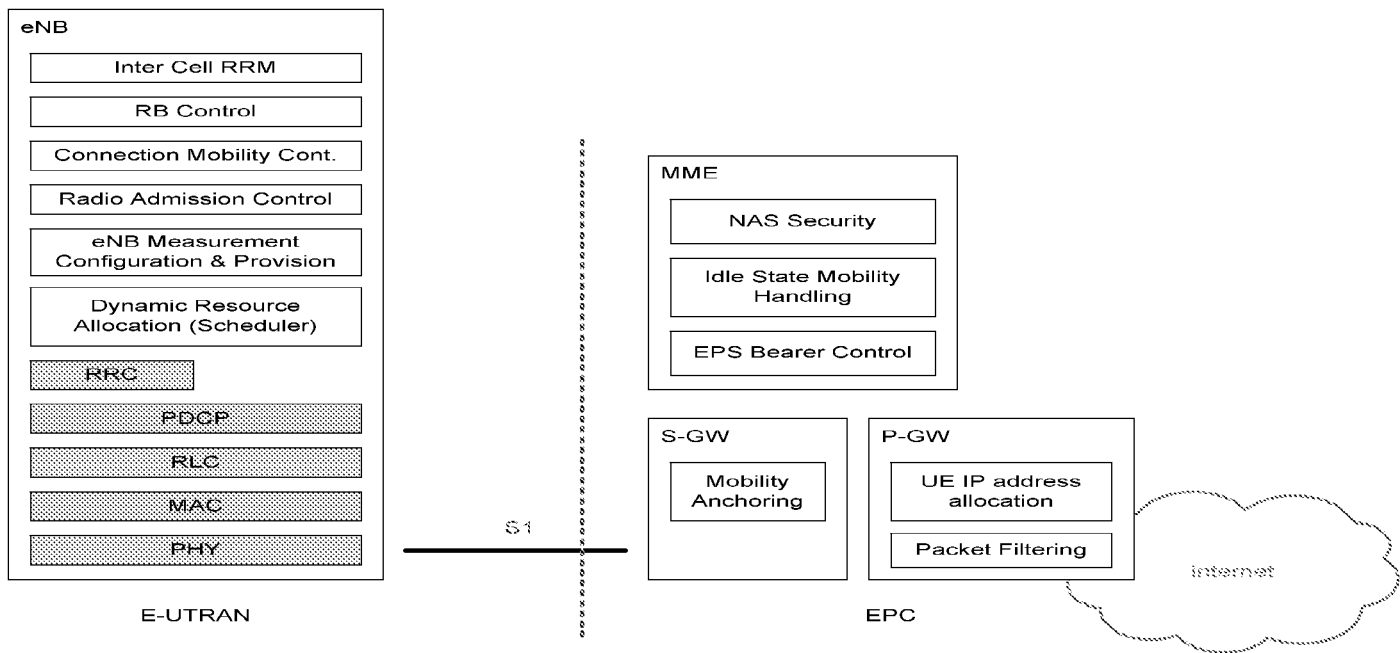


Figure 2: Functional Split between E-UTRAN and EPC

3.1.2 Radio Protocol architecture

The radio protocol architecture of E-UTRAN is divided into the user plane and the control plane.

3.1.2.1 User plane

Figure 3 shows the protocol stack for the user-plane. The user plane protocol stack is comprised of the Packet Data Convergence Protocol (PDCP), Radio Link Control (RLC), and Medium Access Control (MAC), which are terminated at the eNB. The PDCP manages IP packets in the user plane and it performs functionalities such as header compression, security, and re-ordering and retransmission during handover. The RLC layer is mainly responsible for segmentation (and corresponding assembly) of PDCP packets, in order that they fit the size that is actually to be transmitted over the air interface. RLC can operate either in unacknowledged mode or acknowledged mode, where the latter supports retransmissions. The MAC layer performs multiplexing of data from different radio bearers, and it is the one that informs the RLC about the size of the packets to provide, which is decided based on the required QoS of each radio bearer and the current capacity available to the UE.

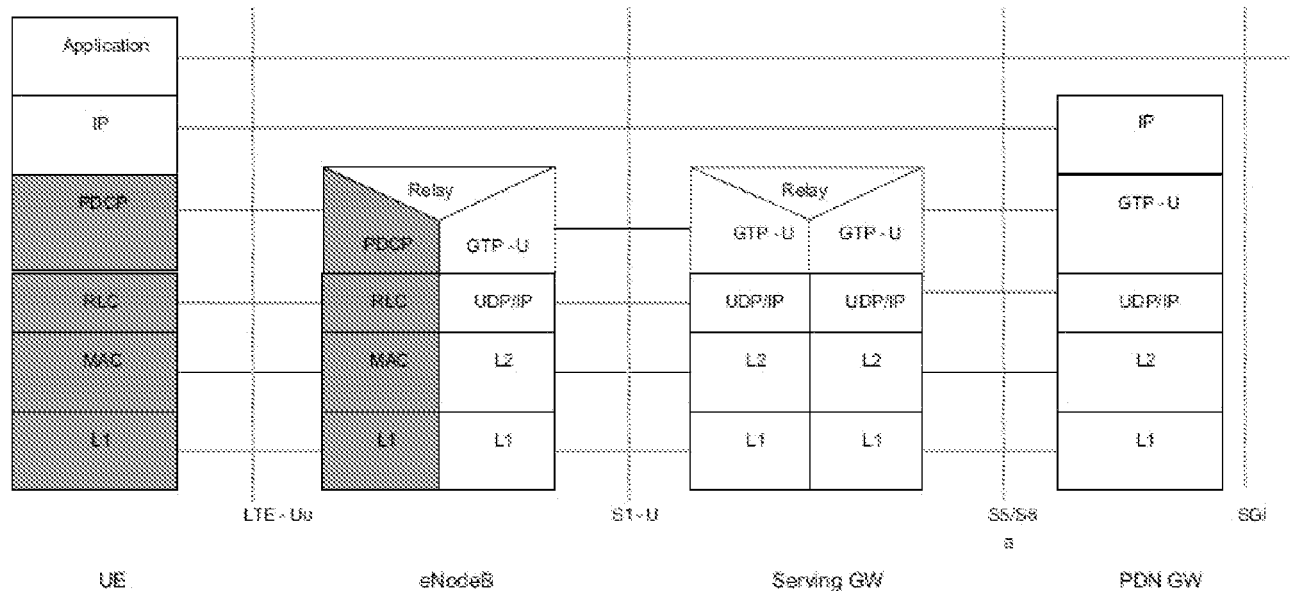


Figure 3: User plane protocol stack

3.1.2.2 Control plane

Figure 4 shows the control plane protocol stack. The layers below the Radio Resource Control (RRC) layer perform the same functionality as in the user plane except that there is no header compression in the control plane. The main functions of the RRC are the broadcasting of system information, RRC connection control (establishment, modification, and release of RRC connection, establishment of signalling radio bearers (SRB) and data radio bearers (DRBs), handover, configuration of lower protocol layers, radio link failure recovery, etc...), and measurement configuration and reporting. The details of the RRC protocol functionalities and procedures can be found in 3GPP TS 36.331.

A UE is uniquely identified over the S1 interface within an eNB with the eNB UE S1AP ID. When an MME receives an eNB UE S1AP ID it stores it for the duration of the UE-associated logical S1-connection for this UE. Once known to an MME this IE is comprised in all UE associated S1-AP signalling. The eNB UE S1AP ID is unique within the eNB, and UEs are assigned new S1AP ID after a handover by the target eNB.

From the MME side, a UE is uniquely identified using the MME UE S1AP ID. When an eNB receives MME UE S1AP ID it stores it for the duration of the UE-associated logical S1 connection for this UE. Once known to an eNB this IE is comprised in all UE associated S1-AP signalling. The MME UE S1AP ID is unique within the MME, and it is changed if the UE's MME changes (for example, handover between two eNBs connected to different MMEs).

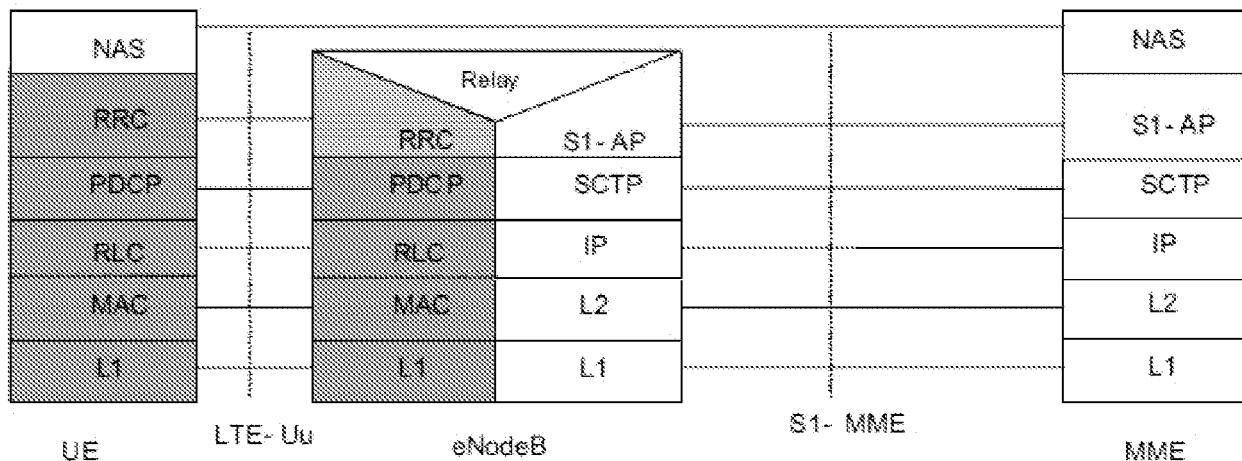


Figure 4: Control plane protocol stack

3.1.2.3 Flow of user plane and control plane data

The flow of user plane and control plane data is illustrated in Figure 5. There is only one MAC entity per UE (unless the UE supports multiple carriers in the case of carrier aggregation) and under this MAC entity, several Hybrid ARQ (HARQ) processes might be running simultaneously for rapid retransmissions. There is a separate RLC entity for each radio bearer and if the radio bearer is configured to use PDCP, there is also one separate PDCP entity for that bearer. A bearer is configured to use PDCP only if it is dedicated to a UE (i.e. multicast and broadcast data do not utilize PDCP both in the control and user plane and the PDCP is used only for dedicated control message in the control plane and for dedicated UL/DL data in the user plane).

At the transmitting side each layer receives a Service Data Unit (SDU) from a higher layer, and sends a Protocol Data Unit (PDU) to the lower layer. For example, PDCP PDUs are sent towards the RLC, and they are RLC SDUs from RLC point of view, which in turn sends RLC PDUs towards the MAC, which are MAC SDUs from the MAC point of view. At the receiving end, the process is reversed, i.e. each layer passing SDUs to the layer above it, where they are perceived as PDUs.

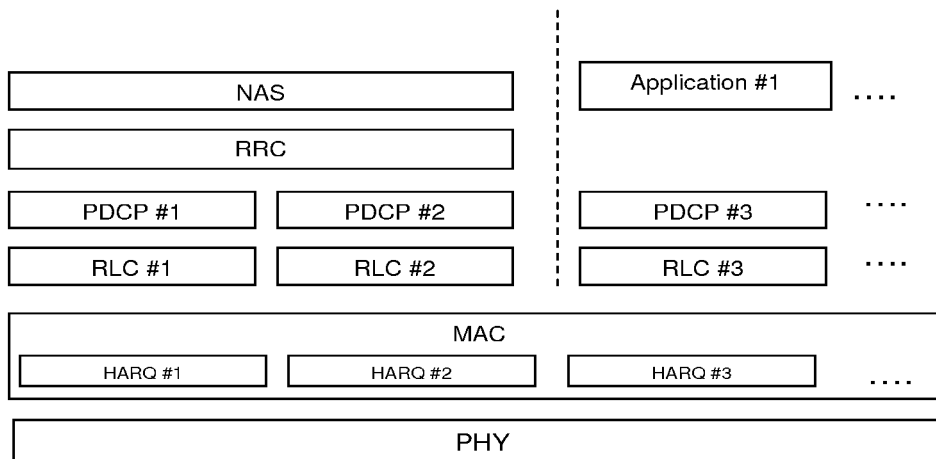


Figure 5: User plane and control plane data flow.

3.1.3 QoS

A UE can have multiple applications running at the same time, each having different QoS requirements (for example, VoIP, browsing, file download ...). In order to support these different requirements, different bearers are set up, each being associated with a QoS. An EPS bearer/E-RAB (Radio Access Bearer) is the level of granularity for bearer level QoS control in the EPC/E-UTRAN. That is, Service Data Flows (SDF) mapped to the same EPS bearer receive the same bearer level packet forwarding treatment (e.g. scheduling policy, queue management policy, rate shaping policy, RLC configuration, etc.) .

One EPS bearer/E-RAB is established when the UE connects to a PDN, and that remains established throughout the lifetime of the PDN connection to provide the UE with always-on IP connectivity to that PDN. That bearer is referred to as the *default* bearer. Any additional EPS bearer/E-RAB that is established to the same PDN is referred to as a *dedicated* bearer. The initial bearer level QoS parameter values of the default bearer are assigned by the network, based on subscription data. The decision to establish or modify a dedicated bearer can only be taken by the EPC, and the bearer level QoS parameter values are always assigned by the EPC.

An EPS bearer/E-RAB is referred to as a GBR bearer if dedicated network resources related to a Guaranteed Bit Rate (GBR) value that is associated with the EPS bearer/E-RAB are permanently allocated (e.g. by an admission control function in the eNB) at bearer establishment/modification. Otherwise, an EPS bearer/E-RAB is referred to as a Non-GBR bearer. A dedicated bearer can either be a GBR or a Non-GBR bearer while a default bearer shall be a Non-GBR bearer.

The EPS bearer service architecture is shown in Figure 6. The packets of an EPS bearer are transported over a radio bearer between the UE and eNB. An S1 bearer transports the packets of an EPS bearer between the eNB and S-GW. An E-RAB is actually a concatenation of these two bearers (i.e. radio bearer and S1 bearer), and the two bearers are mapped on a one to one fashion. An S5/S8 bearer transports the packets of the EPS bearer between the S-GW and P-GW, and completes the EPS bearer. Here also there is a one to one mapping between the E-RAB and S5/S8 bearer.

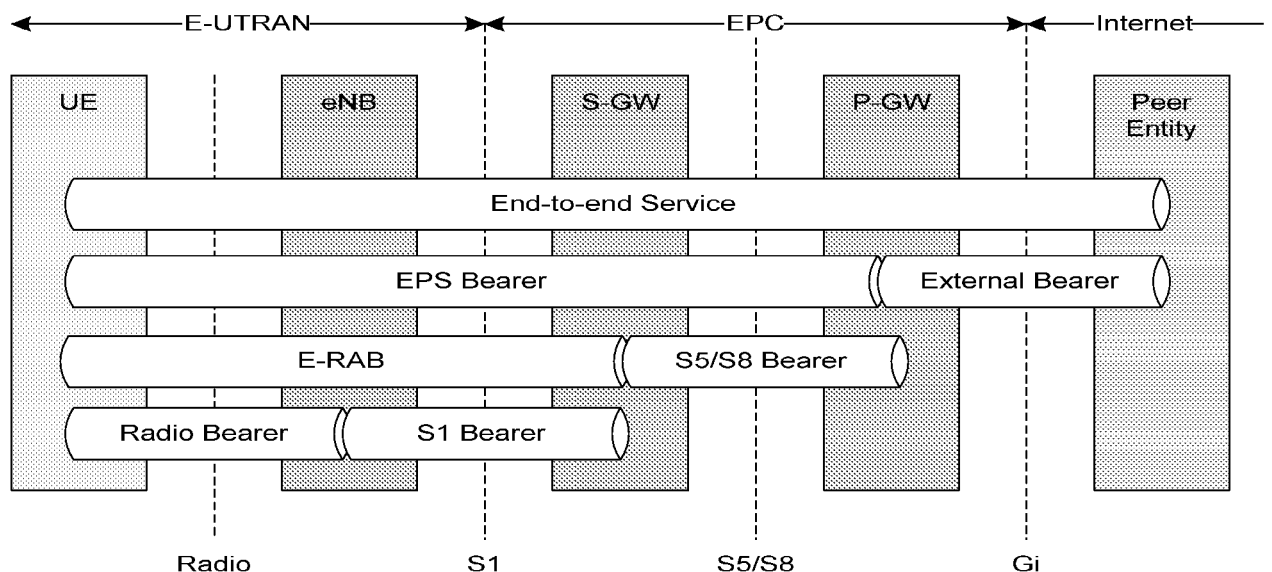


Figure 6: EPS Bearer Service Architecture

The bearer level (i.e. per bearer or per bearer aggregate) QoS parameters are QCI, ARP, GBR, and AMBR. Each EPS bearer/E-RAB (GBR and Non-GBR) is associated with the following bearer level QoS parameters:

- **QoS Class Identifier (QCI):** scalar that is used as a reference to access node-specific parameters that control bearer level packet forwarding treatment (e.g. scheduling weights, admission thresholds, queue management thresholds, link layer protocol configuration, etc.), and that have been pre-configured by the operator owning the eNodeB. Nine QCI values are standardized the detailed requirements of these classes can be found in 3GPP TS 23.203.
- **Allocation and Retention Priority (ARP):** the primary purpose of ARP is to decide whether a bearer establishment / modification request can be accepted or needs to be rejected in case of resource limitations. In addition, the ARP can be used by the eNodeB to decide which bearer(s) to drop during exceptional resource limitations (e.g. at handover).

Each GBR bearer is additionally associated with the following bearer level QoS parameters:

- **Guaranteed Bit Rate (GBR):** the bit rate that can be expected to be provided by a GBR bearer
- **Maximum Bit Rate (MBR):** the maximum bit rate that can be expected to be provided by a GBR bearer. MBR can be greater or equal to the GBR.

Each APN access, by a UE, is associated with a per-APN Aggregate Maximum Bit Rate (APN-AMBR). The APN-AMBR sets the limit on the aggregate bit rate that can be expected to be provided across all Non-GBR bearers and across all PDN connections of the same APN.

Each UE in state EMM-REGISTERED is associated with the bearer aggregate level QoS parameter known as per UE Aggregate Maximum Bit Rate (UE-AMBR). The UE-AMBR limits the aggregate bit rate that can be expected to be provided across all Non-GBR bearers of a UE.

3.1.4 Heterogeneous Networks and Soft/Shared Cells

The use of a so called *heterogeneous deployment* or *heterogeneous network*, as illustrated in Figure 7, consisting of network transmission nodes with different transmit power operating and with overlapping coverage areas, is considered to be an interesting future deployment strategy for cellular networks. In such a deployment, the low-power nodes ("pico nodes") are typically assumed to offer high data rates (Mbit/s), as well as provide high capacity (users/m² or Mbit/s/m²), in the local areas where this is needed/desired, while the high-power nodes ("macro nodes") are assumed to provide full-area coverage. In practice, the macro nodes may correspond to currently deployed macro cells while the pico nodes are later deployed nodes, extending the capacity and/or achievable data rates within the macro-cell coverage area where needed.

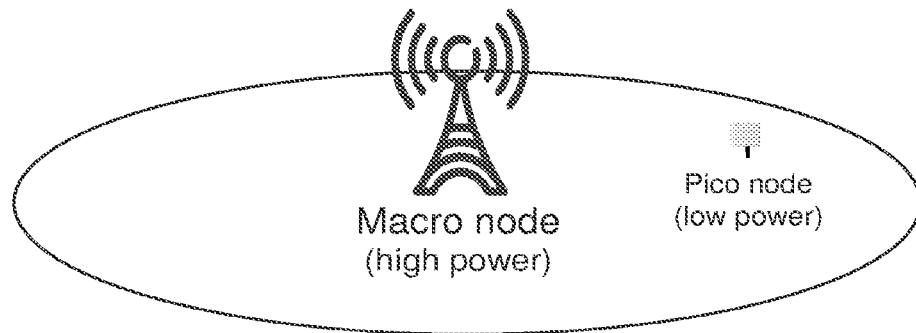


Figure 7: Heterogeneous deployment with a higher-power macro node and a lower-power pico node. In a typical case, there may be multiple pico nodes within the coverage area of a macro node.

A pico node of a heterogeneous deployment may correspond to a cell of its own (a “pico cell”), see Figure 8. This means that, in addition to downlink and uplink data transmission/reception, the pico node also transmits the full set of common signals/channels associated with a cell. In the LTE context this comprises:

- The *Primary and Secondary Synchronization Signals* (PSS and SSS) corresponding to the *Physical Cell Identity* of the pico cell.
- The *Cell-specific reference signals* (CRS), also corresponding to the Physical Cell Identity of the cell. The CRS can e.g. be used for downlink channel estimation to enable coherent demodulation of downlink transmissions.
- The *Broadcast channel* (BCH), with corresponding pico-cell system information¹

As the pico node transmits the common signals/channels, the corresponding pico cell can be detected and selected (connected to) by a terminal (UE, user equipment).

If the pico node corresponds to a cell of its own, also so-called *L1/L2 control signaling* on the PDCCH (as well as PCFICH and PHICH) are transmitted from the pico node to connected terminals, in addition to downlink data transmission on the PDSCH. The L1/L2 control signaling e.g. provides downlink and uplink scheduling information and Hybrid-ARQ-related information to terminals within the cell. This is shown in Figure 8.

¹ Additional system information is transmitted on the PDSCH physical channel

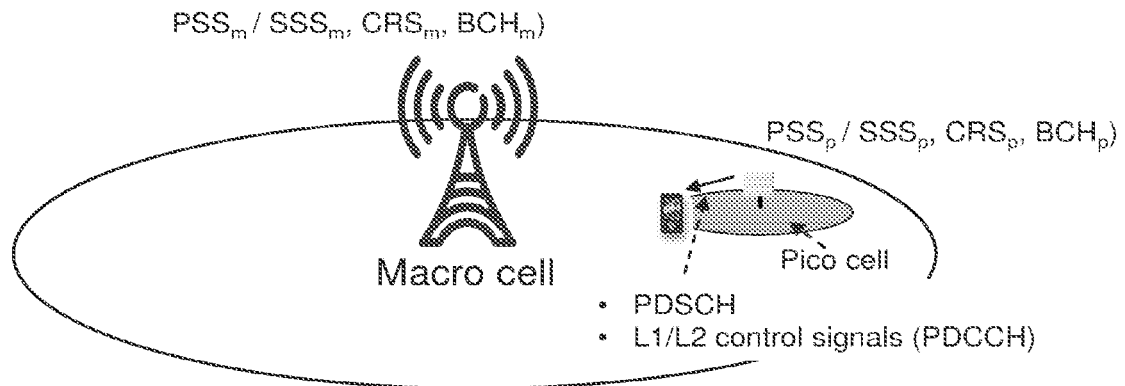


Figure 8: Heterogeneous deployment where the pico node corresponds to a cell of its own (a "pico cell"). The indices "p" and "m" indicate common signals/channels for the pico and macro cell respectively.

Alternatively, a pico node within a heterogeneous deployment may not correspond to a cell of its own but may just provide a data-rate and capacity "extension" of the overlaid macro cell, see e.g. P32215. This is sometimes known as "shared cell" or "soft cell". In this case at least the CRS, PBCH, PSS and SSS are transmitted from the macro node. The PDSCH can be transmitted from the pico node. To allow for demodulation and detection of the PDSCH, despite the fact that no CRS is transmitted from the pico node, DM-RS should be transmitted from the pico node together with the PDSCH. The UE-specific reference signals can then be used by the terminal for PDSCH demodulation/detection. This is shown in Figure 9.

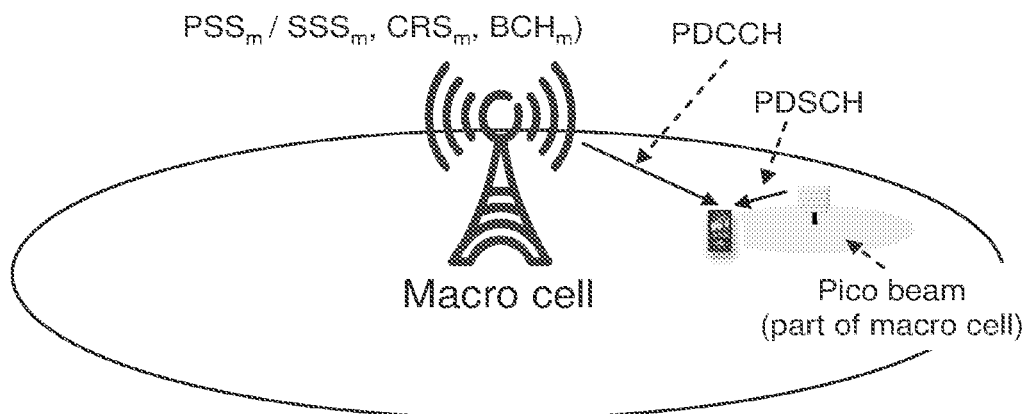


Figure 9: Heterogeneous deployment where the pico node does not correspond to a cell of its own

Transmitting data from a pico node not transmitting CRS as described above requires DM-RS support in the terminal (“non-legacy terminal”). In LTE, DM-RS-based PDSCH reception is supported in Rel-10 and for FDD while for the L1/L2 control signalling, DM-RS-based reception is planned for Rel-11. For terminals not supporting DM-RS-based reception (“legacy terminals”) one possibility in a shared cell setting is to exploit SFN²-type of transmission. In essence *identical* copies of the signals and channels necessary for a legacy terminal are transmitted *simultaneously* from the macro and pico nodes. From a terminal perspective this will look as a single transmission. Such an operation, which is illustrated in Figure 10, will only provide an SINR gain, which can be translated into a higher data rate but not a capacity improvement, as transmission resources cannot be reused across sites within the same cell.

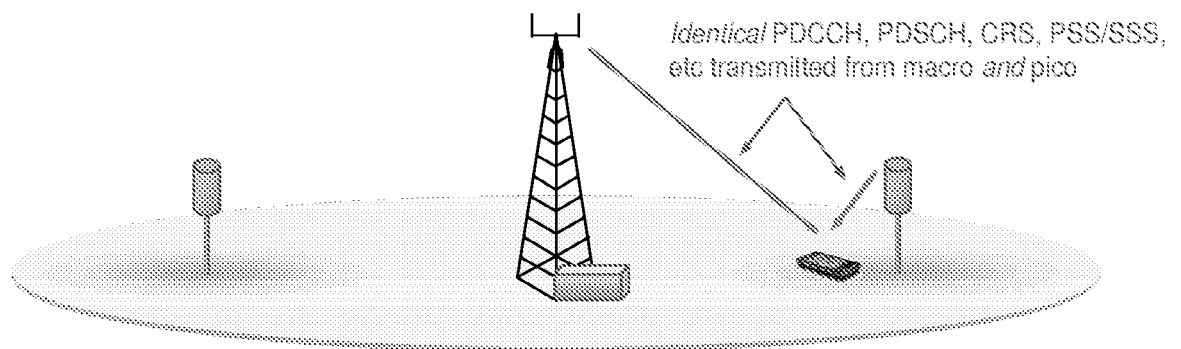


Figure 10: SFN operation with *identical* transmission from macro and pico to a terminal.

If we can assume that the macros are able to provide coverage and the picos are there only for capacity enhancements (i.e. no coverage holes), another alternative architecture is where the UE maintains the macro connectivity all the time (called the “anchor” link), and adds the pico connectivity when it is in the coverage area of the pico (called the “booster” link). When both connections are active, the anchor link can be used either for control signalling while the booster link is used for data. However, it will still be possible to send data also via the anchor link. This is illustrated in Figure 11. Note that in this case, as in the previous cases, the system information is shown to be sent only from the macro, but it is still possible to send it also from the picos.

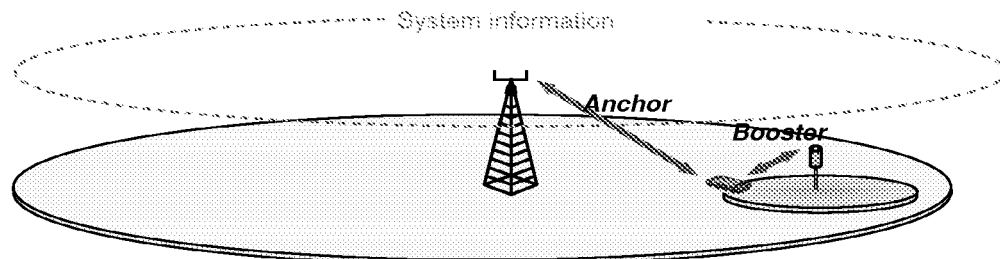


Figure 11: Soft cell operation with the UE having multiple connections with both the anchor and booster.

² Single Frequency Network

3.1.4.1 Protocol architecture for Soft Cells

In order to support multiple connectivity, several architectural options are possible both for the control and user plane. For the user plane, we can have a centralized approach where the PDCP (or even the RLC) is terminated at the anchor only and the booster terminates at the RLC (or even the MAC) level. A decentralized approach will be to have the booster to terminate at the PDCP level. Similar approach can be taken in the control plane (i.e., distributed or centralized PDCP/RLC,) but on top of that we have the additional dimension of centralizing or distributing the RRC. Figure 12 shows an example control and user plane architectures, where the user plane is employing distributed PDCP, while the control plane is centralized at the PDCP level at the anchor. Note that in the figure, user plane aggregation (i.e. the possibility to split the packets belonging to one application data flow over the anchor and booster links) can be realized by using a higher layer aggregation protocol like multi-path TCP (MPTCP).

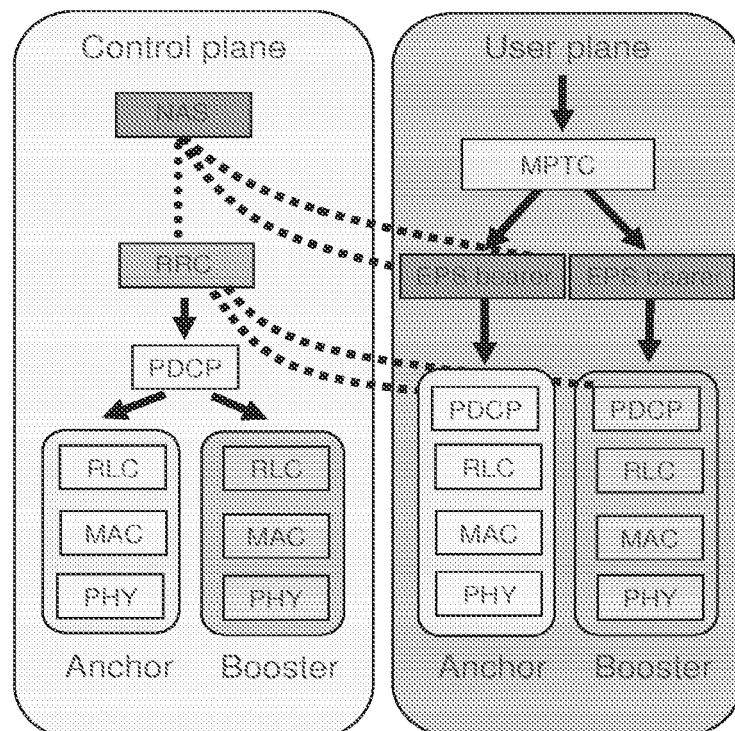


Figure 12: Example protocol architecture for multiple connectivity.

3.1.5 UE measurements

UEs can be configured to report measurements, mainly for the sake of supporting mobility. As specified in 3GPP TS 36.331, the E-UTRAN provides the measurement configuration applicable for a UE in RRC_CONNECTED by means of dedicated signalling, i.e. using the *RRCConnectionReconfiguration* message. The following measurement configurations can be signalled to the UE:

1. **Measurement objects:** These define on what the UE should perform the measurements – such as a carrier frequency. The measurement object may also comprise a list of cells to be considered (white-list or black-list) as well as associated parameters, e.g. frequency- or cell-specific offsets.

2. **Reporting configurations:** These consist of the periodic or event-triggered criteria which cause the UE to send a measurement report, as well as the details of what information the UE is expected to report (e.g. the quantities, such as Received Signal Code Power (RSCP) for UMTS or Reference Signal Received Power (RSRP) for LTE, and the number of cells).
3. **Measurement identities:** These identify a measurement and define the applicable measurement object and reporting configuration. Each measurement identity links one measurement object with one reporting configuration. By configuring multiple measurement identities it is possible to link more than one measurement object to the same reporting configuration, as well as to link more than one reporting configuration to the same measurement object. The measurement identity is used as a reference number in the measurement report.
4. **Quantity configurations:** The quantity configuration defines the filtering to be used on each measurement. One quantity configuration is configured per RAT type, and one filter can be configured per measurement quantity.
5. **Measurement gaps:** Measurement gaps define time periods when no uplink or downlink transmissions will be scheduled, so that the UE may perform the measurements (e.g. inter-frequency measurements where the UE has only one Tx/Rx unit and supports only one frequency at a time). The measurement gaps are common for all gap-assisted measurements

The E-UTRAN configures only a single measurement object for a given frequency, but more than one measurement identity may use the same measurement object. The identifiers used for the measurement object and reporting configuration are unique across all measurement types. It is possible to configure the quantity which triggers the report (RSCP or RSRP) for each reporting configuration.

In LTE, some examples of measurements metric used are the Reference Signal Received Power (RSRP) and Reference Signal Received Quality (RSRQ). RSRP is a cell specific measure of signal strength and it is mainly used for ranking different cells for handover and cell reselection purposes, and it is calculated as the linear average of the power of the Resource Elements (REs) which carry cell-specific Reference Signals (RSs). The RSRQ, on the other hand, also takes the interference into consideration by taking the total received wideband power into account as well.

One of the measurement configuration parameters that UEs receive from their serving eNBs is the *S-measure*, which tells the UE when to start measuring neighbouring cells. If the measured RSRP of the serving cell falls below the S-measure, indicating the signal of the serving cell is not that strong anymore, the UE starts measuring the signal strength of RSs from the neighbouring cells. The S-measure is an optional parameter and different S-measure values can be specified for initiating intra-frequency, inter-frequency and inter-RAT measurements.

Once the UE is enabled for measuring, it can report any of the following:

- The serving cell
- Listed cells (i.e. cells indicated as part of the measurement object);
- Detected cells on a listed frequency (i.e. cells which are not listed cells but are detected by the UE).

There are several measurement configuration parameters that specify the triggering of measurement reports from the UE. The following event-triggered criteria are specified for intra-RAT measurement reporting in LTE:

- **Event A1:** Primary serving cell (PCell) becomes better than absolute threshold.
- **Event A2:** PCell becomes worse than absolute threshold.
- **Event A3:** Neighbour cell becomes better than an offset relative to the PCell.
- **Event A4:** Neighbour cell becomes better than absolute threshold.
- **Event A5:** PCell becomes worse than one absolute threshold and neighbour cell becomes better than another absolute threshold.
- **Event A6:** Neighbour cell becomes better than an offset relative to a secondary cell (SCell)

For inter-RAT mobility, the following event-triggered reporting criteria are specified:

- **Event B1:** Neighbour cell becomes better than absolute threshold.
- **Event B2:** Serving cell becomes worse than one absolute threshold and neighbour cell becomes better than another absolute threshold.

An example of a measurement report triggering event related to handover is A3, and its usage is illustrated in Figure 13. The triggering conditions for event A3 can be formulated as:

$$N > S + HOM \quad (1)$$

where N and S are the signal strengths of the neighbour and serving cells, respectively, and HOM is the handover margin. HOM is the difference between the radio quality of the serving cell and the radio quality needed before attempting a handover. The radio quality is measured either using RSRP or RSRQ (see 36.133 for further explanation).

The UE triggers the intra-frequency handover procedure by sending event A3 report to the eNB. This event occurs when the UE measures that the target cell is better than the serving cell with a margin “HOM”. The UE is configured over RRC when entering a cell and the HOM is calculated from the following configurable parameters:

$$HOM = Of_s + Ocs + Off - Of_n - Ocn + Hys$$

Where:

Of_s is the frequency specific offset of the serving cell

Ocs is the cell specific offset (CIO) of the serving cell

Off is the a3-Offset

Of_n is the frequency specific offset of the neighbor cell

Ocn is the CIO of the neighbor cell

Hys is the hysteresis

If the condition in (1) is satisfied and it remains valid for a certain duration known as Time To Trigger (TTT), the UE sends a measurement report to the serving eNB (in Figure 3, event A3 is satisfied at point A and measurement report is sent at point B in time). When the serving eNB gets the measurement report, it can initiate a handover towards the neighbour.

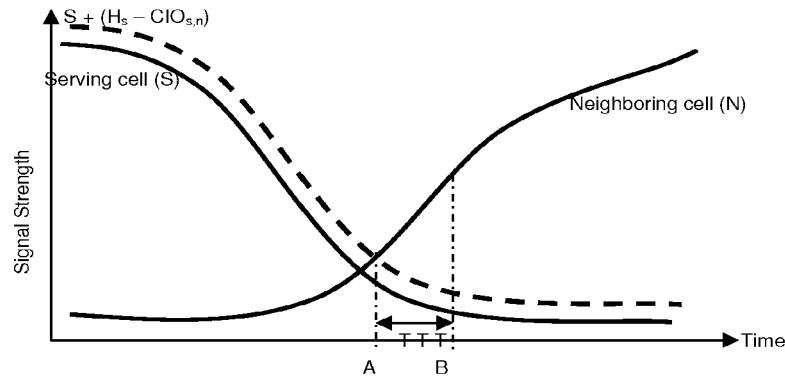


Figure 13: Handover triggering in LTE

In addition to event-triggered reporting, the UE may be configured to perform periodic measurement reporting. In this case, the same parameters may be configured as for event-triggered reporting, except that the UE starts reporting immediately rather than only after the occurrence of an event.

3.1.6 Handover

Handover is one of the important aspects of any mobile communication system, where the system tries to assure service continuity of the User Equipment (UE) by transferring the connection from one cell to another depending on several factors such as signal strength, load conditions, service requirements, etc. The provision of efficient/effective handovers (minimum number of unnecessary handovers, minimum number of handover failures, minimum handover delay, etc.), would affect not only the Quality of Service (QoS) of the end user but also the overall mobile network capacity and performance.

In LTE, UE-assisted, network controlled handover is utilized (3GPP TS 36.300). The handover is based on UE reports, and the UE is moved, if required and possible, to the most appropriate cell that will assure service continuity and quality.

Handover is performed via the X2 connection, whenever available, and if not, using S1 (i.e. involving the Core Network (CN)). The X2 Handover process is shown in **Figure 14**. The handover procedure can be sub divided into three stages of *preparation (initiation)*, *execution* and *completion*.

During the preparation stage, based on the measurement results the source eNB is getting from the UE, the source eNB decides whether to handover the connection to another eNB or not. If the decision is to handover, the source eNB sends a HANDOVER REQUEST message to the target eNB. The source eNB must indicate the cause of the HO in this message, which can be, e.g.,

- Handover Desirable for Radio Reasons,
- Resource Optimisation Handover,
- Reduce Load in Serving Cell

Thus the target eNB knows that the HO is due to resource optimization or to reduce the load in the serving cell. If the target eNB is able to admit the UE, a message is sent to the UE to initiate the handover, and we enter the handover execution state. DL data arriving at the source eNB for the UE are then forwarded to the new target eNB.

The handover completion stage is entered once the target eNB and the UE are synchronized and a handover confirm message (step 11 of Figure 6) is received by the target eNB. After a proper setup of the connection with the target eNB is performed (which comprise the switching of the DL path in the serving gateway), the old connection is released and any remaining data in the source eNB that is destined for the UE is forwarded to the target eNB. Then normal packet flow can ensue through the target eNB.

3.2 Introduction of the example embodiments

LTE currently supports only one to one connections between UEs and eNBs. As such, when a handover is initiated, the target is asked to admit all the bearers of the UE. If for some reason, such as overload situation, that some of the bearers can't be admitted at the target, the source can either cancel the handover (and possibly try another candidate target) or accept it and handover the UE to the target, which will result in the dropping of the non-admitted bearers. This can have severe consequences on the overall experience of the user.

Current specifications do not allow the setup of bearers in parallel and in multiple eNBs for the same UE, which is needed for enabling multiple connectivity. This would allow an optimal distribution of bearers depending on their QoS and UL/DL requirements.

Some of the example embodiments presented herein addresses the problem of mobility procedures allowing for distribution of UE bearers across multiple eNBs with the possibility to connect a UE to multiple eNBs

Electronic Acknowledgement Receipt

EFS ID:	13403354
Application Number:	61678772
International Application Number:	
Confirmation Number:	2882
Title of Invention:	Selective Handover
First Named Inventor/Applicant Name:	Oumer Teyeb
Customer Number:	11754
Filer:	Sarah Janelle Rodriguez
Filer Authorized By:	
Attorney Docket Number:	PG19873US00
Receipt Date:	02-AUG-2012
Filing Date:	
Time Stamp:	14:19:16
Application Type:	Provisional

Payment information:

Submitted with Payment	yes
Payment Type	Credit Card
Payment was successfully received in RAM	\$870
RAM confirmation Number	615
Deposit Account	
Authorized User	

File Listing:

Document Number	Document Description	File Name	File Size (Bytes)	Exhibitors' Exhibit	Page 23
		AT&T v. Innovative Software	Message Digest	Part 1 of 2	Page 23

1	Provisional Cover Sheet (SB16)	Provisional_Patent_Application_Cover_Sheet.pdf	2071737 f6ba89dd1f3a6f9f204b08e740d800b5f5d89314	no	4
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Information:					
2		Provisional_Patent_Application_PG19873US00_P38076_Specification_1.pdf	1145311 76ff11edcaa0e6a0bd408127b860d05aa86d8582	yes	48
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	Drawings-other than black and white line drawings		16	16	
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	Drawings-other than black and white line drawings		18	18	
	Specification		19	49	
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	Drawings-other than black and white line drawings		16	16	
	Specification		17	67	

Petitioners' Exhibit 1006, p. 24

Warnings:					
Information:					
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Information:					
6	Fee Worksheet (SB06)	fee-info.pdf	31191 760d1e9ac88608e807108904d720e7b52ccf90aa	no	2
Warnings:					
Information:					
Total Files Size (in bytes):			6681560		
This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503. <u>New Applications Under 35 U.S.C. 111</u> If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application. <u>National Stage of an International Application under 35 U.S.C. 371</u> If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course. <u>New International Application Filed with the USPTO as a Receiving Office</u> If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.					

4 Brief summary of the example embodiments

According to some of the example embodiments, different mechanisms for enabling multiple connectivity between a UE and multiple cells are proposed. In related lVds (P38076, P38135, and P38145), the basic concept of selective handover as well as the required changes in the communication of eNBs involved in the selective handover, and the communication with the UE have been described. According to some of the example embodiments, the communication aspects between the eNBs and the CN to enable selective handovers is presented.

5 Detailed description of the example embodiments

5.1 Non-limiting implementation example

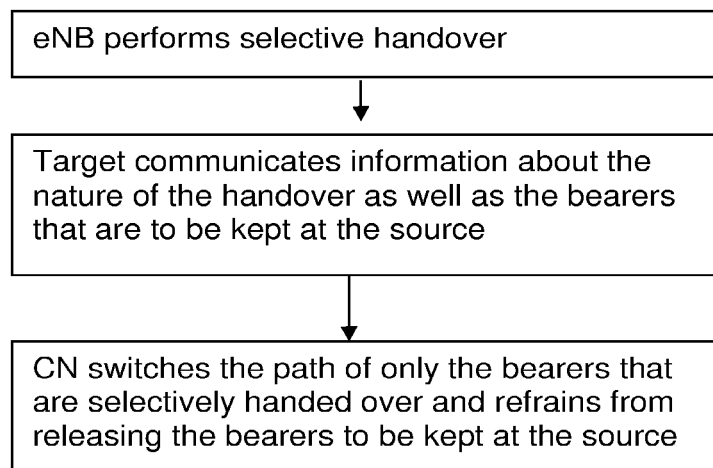


Figure 15: a non-limiting example implementation

A non-limiting example implementation is provided in Figure 15. The details of the example embodiments are given below. For the sake of brevity, the descriptions below treat mostly the case of dual connectivity with two cells, but the ideas are equally applicable for the case where the UE is connected to more than two cells at the same time.

With selective handover and multiple connectivity (P38076, P38135, P38145), only the paths of the bearers that are selectively handed over to the target are to be switched. However, as described in Section 4.1.6, legacy MME operation assumes that bearers not comprised in the path switch are to be released and as such, bearer release operation is performed on them. According to some of the example embodiments, the PATH SWITCH REQUEST message is modified to prevent this. There are several ways of achieving this:

- A new IE (e.g. *Selective Handover*) is introduced in the message, which tells the handover is a selective handover. Or
- A new IE (e.g. E-RAB Not To Be Switched in Downlink List) is introduced in the message, which explicitly lists the bearers that are to be kept at the source. Or
- A new IE (e.g. E-RAB To Be Released in Downlink List) is introduced in the message, which explicitly lists the bearers that are to be released.

When the MME receives a PATH SWITCH REQUEST message with one of these IEs set to true, it will not release the bearers that are to be kept in the source (i.e. all the bearers not comprised in the E-RAB To Be Switched in Downlink List in case “Selective Handover” IE is used, or the bearers comprised in the “E-RAB Not To Be Switched in Downlink List” or the bearers not comprised in the “E-RAB To Be Released in Downlink List”).

According to some of the example embodiments, the PATH SWITCH REQUEST is kept as in legacy LTE, but the MME is configured (e.g. via the OAM system) so to avoid E-RAB terminations for the E-RABs not listed in the PATH SWITCH REQUEST message. The later decision could be taken either unconditionally or depending on source node and target node identities (which can be derived by the *Source MME UE S1AP ID* IE and *Source MME GUMMEI* IE in PATH SWITCH REQUEST message and by the ID of the target node that is sending the message). That is, the MME can act differently to the same message depending on the source and target nodes involved in this handover.

According to some of the example embodiments, the MME upon reception of an updated PATH SWITCH REQUEST message that comprises the bearers to be kept at the source node, either implicitly or explicitly as discussed above, will comprise these bearers in the “Bearer contexts to be modified” field of the MODIFY BEARER REQUEST message that it is sending to the SGW, but keeping their context information, such as the TEIDs.

According to some of the example embodiments, the MODIFY BEARER REQUEST message is modified to comprise a new IE (e.g. “Bearer context to be kept”) which is a list similar to the “Bearer context to be released” (i.e. it comprises only the list of bearer IDs while the “Bearer context to be modified” comprises details of the bearer context). That way, the size of the MODIFY BEARER REQUEST message can be reduced.

In legacy operation, if the path switch was not successful in the CN for some bearers, the MODIFY BEARER RESPONSE comprises these bearers in the “Bearer Contexts marked for removal” field, and the PATH SWITCH REQUEST ACKNOWLEDGE will comprise these in the “E-RAB To Be Released List” list. The eNB is then expected to release the corresponding bearers.

According to some of the example embodiments, when the MME gets a MODIFY BEARER RESPONSE that comprises bearers to be removed, it will refrain from removing them, but still comprises them in the PATH SWITCH REQUEST ACKNOWLEDGE message that sends to the target.

According to some of the example embodiments, the target upon receiving a PATH SWITCH REQUEST ACKNOWLEDGE that comprises some entries in the “E-RAB To Be Released List”, communicates this information to the source. This information can be conveyed via a new X2 message.

According to some of the example embodiments, the source, upon receiving such information that certain bearer(s) were not able to be switched to the new target, will decide whether to keep them with itself (i.e. considering conditions such as load, the radio link with the concerned UE, the QoS requirement of the bearer, etc.). The source communicates this decision to the target via a new X2 message. This message can comprise, for example, a list of all the bearers, along with the source’s decision to keep the bearer or not.

According to some of the example embodiments, when the target gets a list which shows the bearers that the source is willing to keep or not, it communicates this to the MME (e.g. via a new S1 message) and deletes the context of all the bearers.

According to some of the example embodiments, when the MME gets this list, it will release the bearers that the source is not willing to keep, and for those that the source is willing to keep, it will initiate construct a MODIFY BEARER REQUEST that will convey to the CN that the original path is to be restored.

According to some of the example embodiments, a user plane proxy is introduced in the system that hides the switching procedures described above from the core network. That is, the proxy, when receiving a PATH SWITCH message that indicates that the handover that is selective, will short circuit the message, and performs the local switching by itself. That is, from the CN point of the view, the UE is still connected to the anchor, and all the data belonging to that UE are routed to the anchor via the proxy. However, as the proxy knows which bearers belong to the anchor and which to the booster, it will route the data properly to the right node.

According to some of the example embodiments, the proxy is co-located at the anchor node. In this case, if a selective handover is started that requests a switching of the anchor (as described in P38076), then the PATH SWITCH REQUEST to be sent to the CN should comprise all the bearers of the UE, as the new point of termination of all the bearers from the CN point of view is now the new anchor.

An LTE system has been assumed throughout the discussion of the example embodiments. However, most of the ideas discussed above can become readily applicable to mobile broadband systems such as High Speed Packet Access (HSPA).

6 Example advantages of the example embodiments

The ideas discussed in relation to the example embodiments make it possible to perform handovers selectively between a source and a target eNB, thereby creating more system flexibility than the legacy way of performing handover where a UE is completely handed over to the target. Some advantages of this are:

- Possibility to keep all the UE bearers ongoing as the bearers that the target was not able to admit can be kept at the source
- Possibility to trigger handover at a bearers level rather than at UE level. For example, the source eNB can keep the bearers that can't tolerate discontinuity such as VoIP services with itself until the radio conditions of the source are at much lower quality than the target, while bearers that are very capacity hungry but more tolerant to interruptions such as file download can be handed over to the target even if the radio conditions at the source are not that bad.
- Possibility to maintain control plane at one eNB, while sharing the data load at several eNBs. This opens several opportunities such as network sharing. For example, several operators can share the pico nodes for data bearers, while maintaining the signaling radio bearers only at their macros.
- Control plane diversity, such as sending of handover command from the source and/or targets or sending of the measurement report towards targets becomes rather straightforward with multiple connectivity.
- RLF on the booster or anchor node can be recovered faster. Booster recovery is straightforward as the UE context resides at the anchor, and anchor recovery also becomes fast as the booster can fetch the context easily from the network.

7 Figures

7.1 Example node configurations

The following example nodes may be configured to perform the example operations discussed herein.

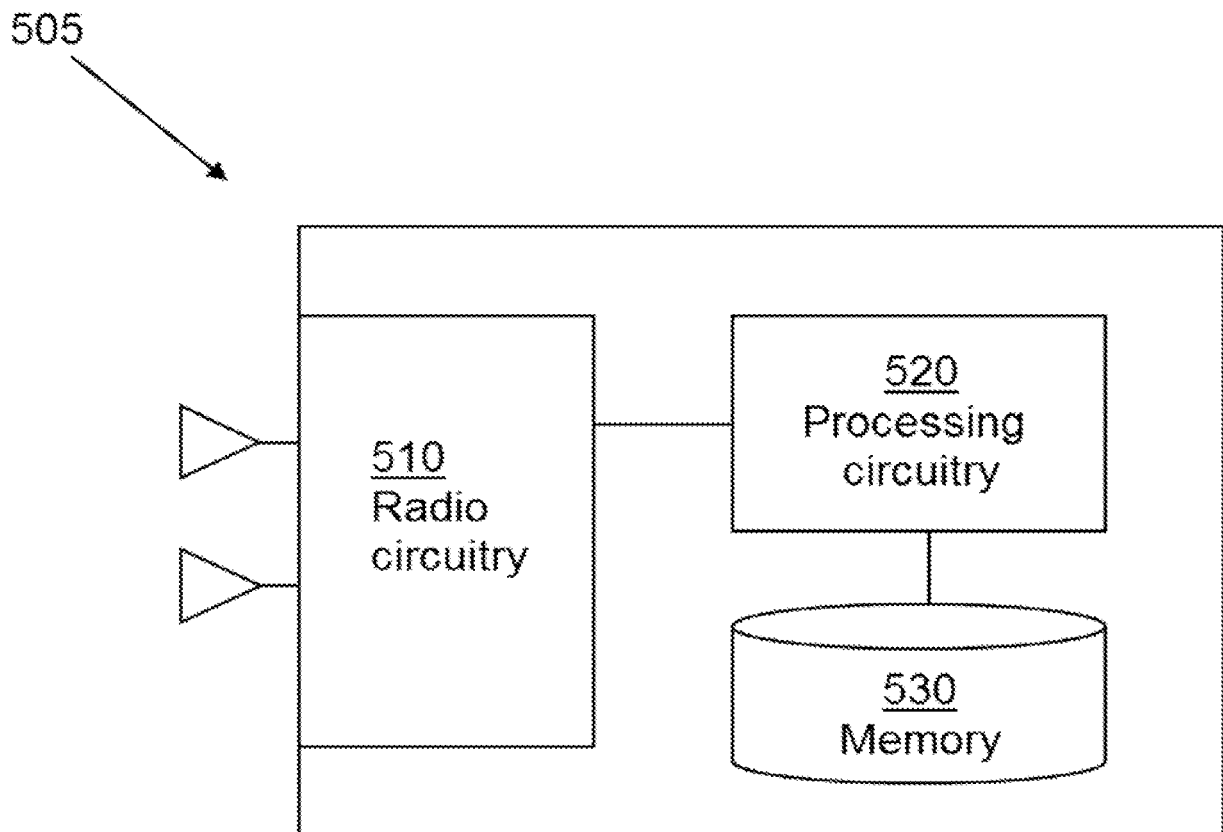


Figure 16 – example core network node configuration

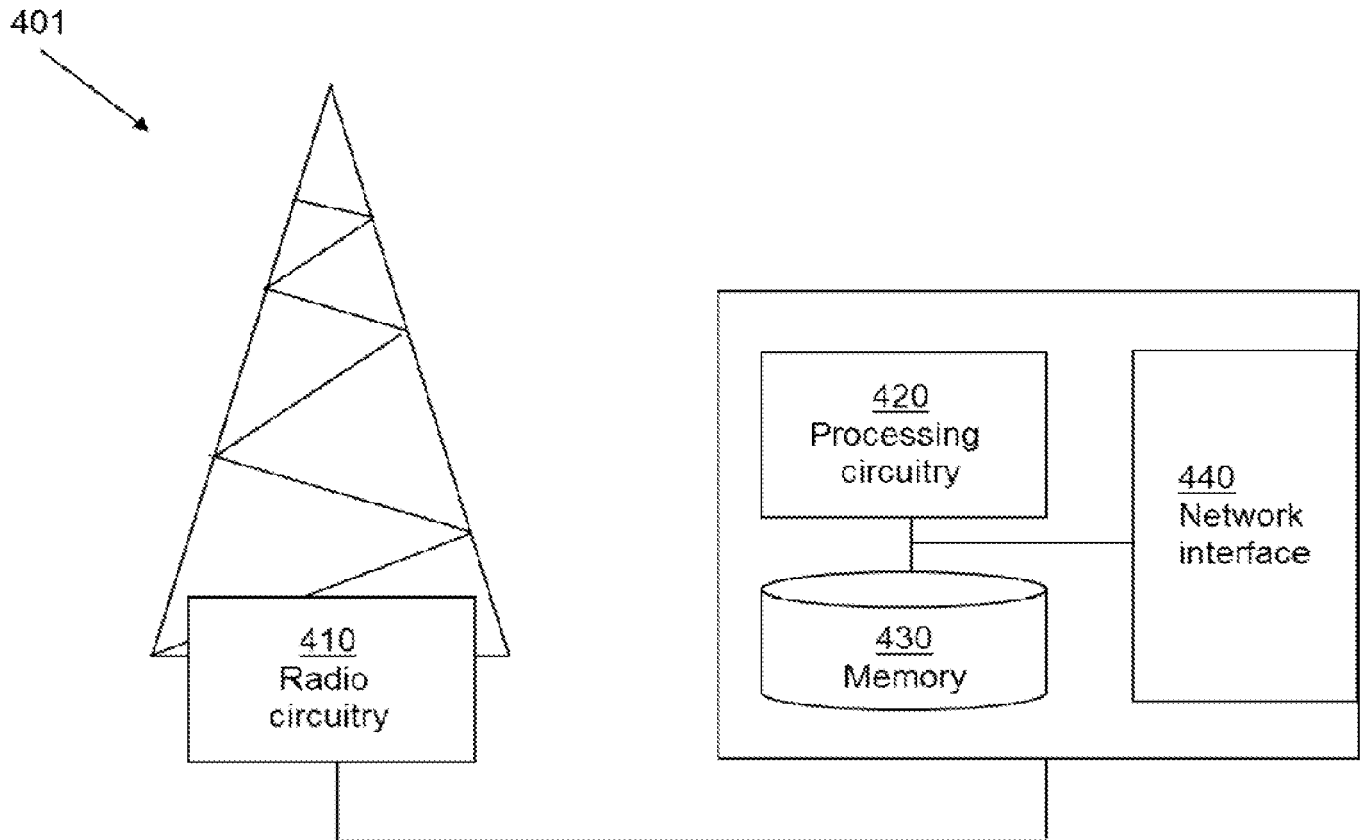


Figure 17 – Example target base station configuration

The example embodiments presented herein may be utilized in a wireless network, which may further comprise a target base station 401, as illustrated in Figure 17. The wireless network may also comprise a core network node 505, as illustrated in 16. It should be appreciated that the examples provided in Figures 16 and 17 are shown merely as non-limiting examples.

As shown in Figure 17, the example target base station 401 may comprise processing circuitry 420, a memory 430, radio circuitry 410, and at least one antenna. The processing circuitry 420 may comprise RF circuitry and baseband processing circuitry (not shown). In particular embodiments, some or all of the functionality described above as being provided by a mobile base station, a base station controller, a relay node, a NodeB, an enhanced NodeB, and/or any other type of mobile communications node may be provided by the processing circuitry 420 executing instructions stored on a computer-readable medium, such as the memory 430 shown in Figure 17.

Alternative embodiments of the target base station 401 may comprise additional components responsible for providing additional functionality, comprising any of the functionality identified above and/or any functionality necessary to support the solution described above. In other example embodiments, a network node may be not equipped with a radio interface or radio circuitry 410.

It should also be appreciated that the processing circuitry (or any other hardware and/or software unit configured to execute operations and/or commands) of the base station 401 illustrated in Figure 17 may be configured to configure to provide a selective handover procedure. It should also be appreciated that the example base station of Figure 17 may be a source and/or target base station.

According to some of the example embodiments, the source base station may be functioning as either a booster or anchor node, while the target base station may also function as either a booster or anchor node. Thus, according to some of the example embodiments, the selective handover procedure may take place from an anchor (source) to a booster (target) node, from a booster (source) node to another booster (target) node, or from a booster (source) node to an anchor (target) node.

An example of a core network node is provided in Figure 16. It should be appreciated that the core network node may be a MME, S4-SGSN, or a SGSN. The example core network node 505 may comprise processing circuitry 520, a memory 530, radio circuitry 510, and at least one antenna. The radio circuitry may comprise RF circuitry and baseband processing circuitry (not shown). In particular embodiments, some or all of the functionality described above as being provided by mobile communication devices or other forms of wireless device may be provided by the processing circuitry 520 executing instructions stored on a computer-readable medium, such as the memory 530 shown in Figure 16.

Alternative embodiments of the core network node 505 may comprise additional components responsible for providing additional functionality, comprising any of the functionality identified above and/or any functionality necessary to support the example embodiments described herein.

It should be appreciated that the processing circuitry (or any other hardware and/or software unit configured to execute operations and/or commands) of the user equipment may be configured to provide path switching or relocation.

7.2 Flow diagrams

It should be appreciated that the terms 'source base station' and 'target base station' have been used to describe the example embodiments herein. It should be appreciated that the source and target in general may be thought of as cells. However, it is the base stations which send the messages described herein on behalf of their respective cells.

Figures 18A and 18B are a flow diagram depicting example operations which may be taken by a core network node 505 of Figure 16 in a path switching or relocation of at least a sub-set of bearers associated with a user equipment. It should also be appreciated that Figures 18A and 18B comprise some operations which are illustrated with a darker border and some operations which are illustrated with a lighter border. The operations which are comprised in a darker border are operations which are comprised in the broadest example embodiment. The operations which are comprised in a lighter border are example embodiments which may be comprised in, or a part of, or are further operations which may be taken in addition to the operations of the boarder example embodiments. It should be appreciated that these operations need not be performed in order. Furthermore, it should be appreciated that not all of the operations need to be performed. The example operations may be performed in any order and in any combination.

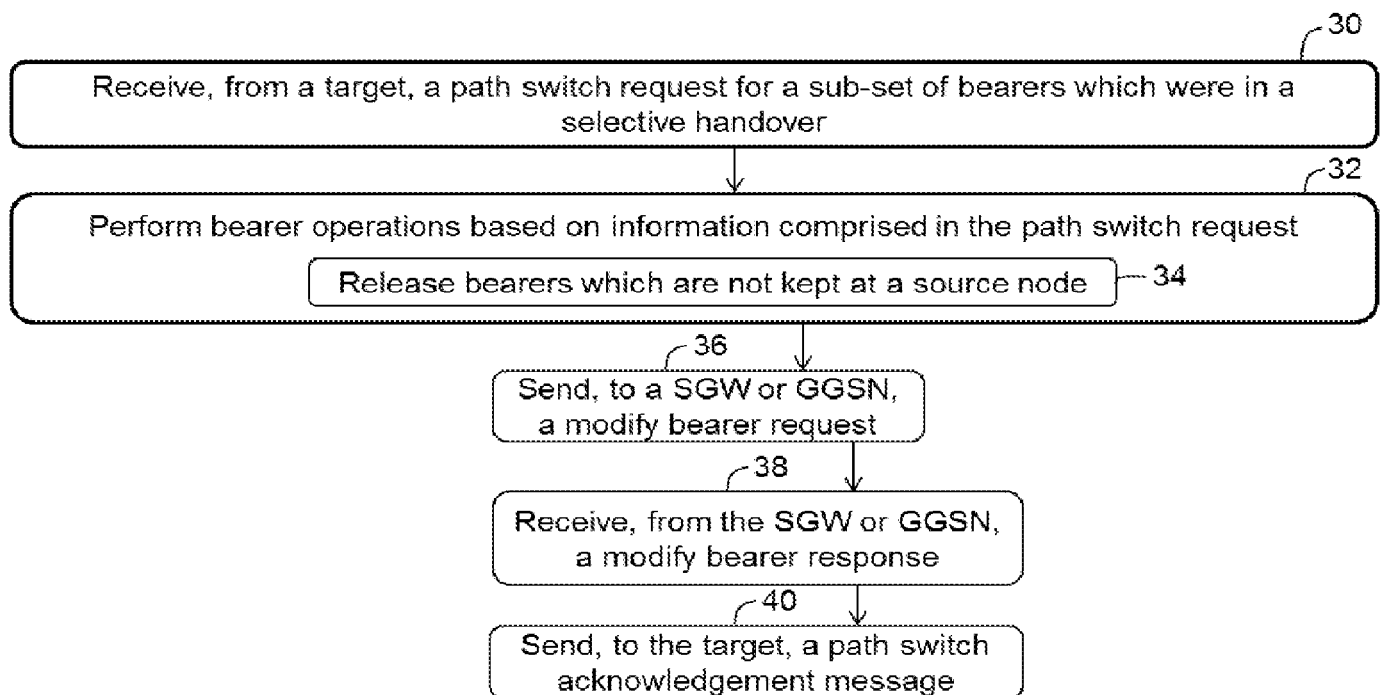


Figure 18A – example operations of a core network node

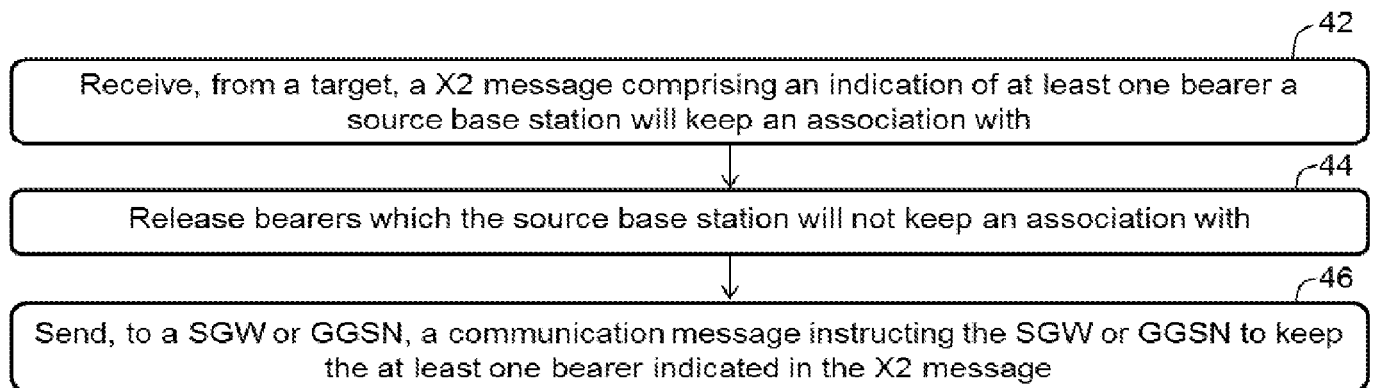


Figure 18B – example operations of a core network node

Figure 19 is a flow diagram depicting example operations which may be taken by the target base station 401 of Figure 17 in the providing a handover of at least a sub-set of bearers associated with a user equipment. It should also be appreciated that Figure 19 comprises some operations which are illustrated with a darker border and some operations which are illustrated with a lighter border. The operations which are comprised in a darker border are operations which are comprised in the broadest example embodiment. The operations which are comprised in a lighter border are example embodiments which may be comprised in, or a part of, or are further operations which may be taken in addition to the operations of the boarder example embodiments. It should be appreciated that these operations need not be performed in order. Furthermore, it should be appreciated that not all of the operations need to be performed. The example operations may be performed in any order and in any combination.

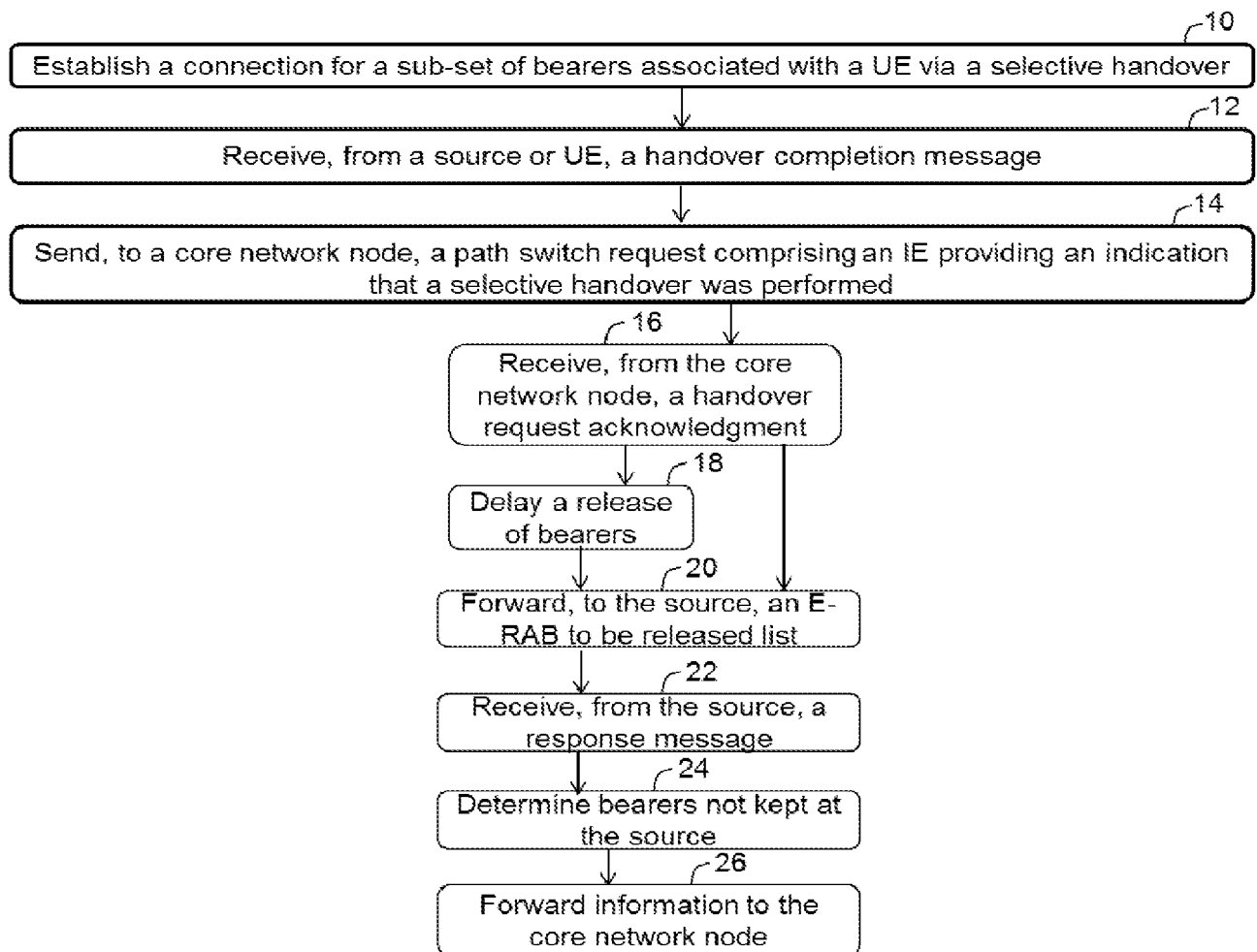


Figure 19 – example operations of a target base station

8 Conclusion

It should be noted that although terminology from 3GPP LTE has been used herein to explain the example embodiments, this should not be seen as limiting the scope of the example embodiments to only the aforementioned system. Other wireless systems, comprising WCDMA, WiMax, UMB, WiFi and GSM, may also benefit from the example embodiments disclosed herein.

The description of the example embodiments provided herein have been presented for purposes of illustration. The description is not intended to be exhaustive or to limit example embodiments to the precise form disclosed, and modifications and variations are possible in light of the above teachings or may be acquired from practice of various alternatives to the provided embodiments. The examples discussed herein were chosen and described in order to explain the principles and the nature of various example embodiments and its practical application to enable one skilled in the art to

utilize the example embodiments in various manners and with various modifications as are suited to the particular use contemplated. The features of the embodiments described herein may be combined in all possible combinations of methods, apparatus, modules, systems, and computer program products. It should be appreciated that the example embodiments presented herein may be practiced in any combination with each other.

It should be noted that the word “comprising” does not necessarily exclude the presence of other elements or steps than those listed and the words “a” or “an” preceding an element do not exclude the presence of a plurality of such elements. It should further be noted that any reference signs do not limit the scope of the claims, that the example embodiments may be implemented at least in part by means of both hardware and software, and that several “means”, “units” or “devices” may be represented by the same item of hardware.

Also note that terminology such as user equipment should be considered as non-limiting. A device or user equipment as the term is used herein, is to be broadly interpreted to comprise a radiotelephone having ability for Internet/intranet access, web browser, organizer, calendar, a camera (e.g., video and/or still image camera), a sound recorder (e.g., a microphone), and/or global positioning system (GPS) receiver; a personal communications system (PCS) user equipment that may combine a cellular radiotelephone with data processing; a personal digital assistant (PDA) that can comprise a radiotelephone or wireless communication system; a laptop; a camera (e.g., video and/or still image camera) having communication ability; and any other computation or communication device capable of transceiving, such as a personal computer, a home entertainment system, a television, etc. It should be appreciated that the term user equipment may also comprise any number of connected devices.

The various example embodiments described herein are described in the general context of method steps or processes, which may be implemented in one aspect by a computer program product, embodied in a computer-readable medium, comprising computer-executable instructions, such as program code, executed by computers in networked environments. A computer-readable medium may comprise removable and non-removable storage devices comprising, but not limited to, Read Only Memory (ROM), Random Access Memory (RAM), compact discs (CDs), digital versatile discs (DVD), etc. Generally, program modules may comprise routines, programs, objects, components, data structures, etc. that perform particular tasks or implement particular abstract data types. Computer-executable instructions, associated data structures, and program modules represent examples of program code for executing steps of the methods disclosed herein. The particular sequence of such executable instructions or associated data structures represents examples of corresponding acts for implementing the functions described in such steps or processes.

In the drawings and specification, there have been disclosed exemplary embodiments. However, many variations and modifications can be made to these embodiments. Accordingly, although specific terms are employed, they are used in a generic and descriptive sense only and not for purposes of limitation, the scope of the embodiments being defined by the following summary of example embodiments.

9 Abbreviations

3GPP	3 rd Generation Partnership Project
AMBR	Aggregate Maximum Bit Rate
AP	Application Protocol
ARP	Allocation and Retention Priority
ARQ	Automatic Repeat reQuest
BCH	Broadcast Channel
CIO	Cell Individual Offset
CN	Core Network
CRS	Cell specific Reference Symbol
CSG	Closed Subscriber Group
DL	Downlink
DM	Demodulation
DRB	Data Radio Bearer
E-UTRAN	Evolved UMTS Terrestrial Radio Access Network
eNB/eNodeB	enhanced Node B(base station)
EPC	Evolved Packet Core
EPS	Evolved Packet System
GBR	Guaranteed Bit Rate
GUMMEI	Globally Unique Mobility Management Entity Identifier
HARQ	Hybrid Automatic Repeat reQuest
HeNB	Home eNB
HO	Handover
HOM	Handover Margin
HSPA	High-Speed Packet Access
IE	Information Element
ID	Identity
IP	Internet Protocol
LTE	Long Term Evolution
MAC	Medium Access Control
MBR	Maximum Bit Rate
MME	Mobility Management Entity
MTCP	Multi-path Transmission Control Protocol
NAS	Non-Access Stratum
OAM	Operation and Maintenance
P-GW	PDN Gateway
PBCH	Physical Broadcast CHannel

PCell	Primary Cell
PCFICH	Physical Control Format Indicator CHannel
PCI	Physical Cell Identity
PDCCH	Physical Downlink Control CHannel
PDCP	Packet Data Convergence Protocol
PDN	Packet Data Network
PDSCH	Physical Downlink Shared CHannel
PDU	Packet Data Unit
PHICH	Physical Hybrid ARQ Indicator CHannel
PSS	Primary Synchronization Signal
QCI	QoS Class Identifier
QoS	Quality of Service
RLC	Radio Link Control
RAB	Radio Access Bearer
RAT	Radio Access Technology
RE	Resource Element
RRC	Radio Resource Control
RRH	Remote Radio Head
RRM	Radio Resource Management
RS	Reference Signal
RSCP	Received Signal Code Power
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
S-GW	Serving Gateway
SCell	Secondary Cell
SCTP	Stream Control Transmission Protocol
SDF	Service Data Flow
SDU	Service Data Unit
SRB	Signaling Radio Bearer
SRVCC	Single Radio Voice Call Continuity
SSS	Secondary Synchronization Signal
TCP	Transmission Control Protocol
TTT	Time To Trigger
UE	User Equipment
UL	Uplink
VoIP	Voice over Internet Protocol

10 Summary of example embodiments

In some instances, the summary of example embodiments provides specific names for messages and information elements which are passed throughout the network. It should be appreciated that such names are used merely as an examples. One purpose of the summary of example embodiments is to highlight the function of such messages and information elements. It should further be appreciated that any messages mentioned herein may be applied to any new or existing interface of the wireless network.

1. A method, in a target base station, for providing a handover of at least a sub-set of bearers associated with a user equipment, the method comprising:
 - establishing **(10)** a connection for the sub-set of bearers associated with the user equipment via a selective handover procedure;
 - receiving **(12)**, from a source base station or a user equipment, a handover competition message for the sub-set of bearers associated with the user equipment; and
 - sending **(14)**, to a core network node, a path switch request, said path switch request comprising an information element providing an indication that a selective handover procedure was performed.

According to some of the example embodiments, the source base station may be functioning as either a booster or anchor node, while the target base station may also function as either a booster or anchor node. Thus, according to some of the example embodiments, the selective handover procedure may take place from an anchor (source) to a booster (target) node, from a booster (source) node to another booster (target) node, or from a booster (source) node to an anchor (target) node.
2. The method of example embodiment 1, wherein the path switch request further comprises a list of bearers which are still to be kept established with a source base station.

According to some of the example embodiments, since a selective handover procedure may be indicated in the path switch request, the core network node may know not to release bearers that are to be kept with the source base station.
3. The method of any of example embodiments 1-2, wherein the path switch request further comprises a list of bearers which are to be released.
4. The method of any of example embodiments 1-3, further comprising receiving **(16)**, from the core network node, a path switch request acknowledgement message.

5. The method of example embodiments 4, wherein the path switch request acknowledgement comprises an E-RAB to be released list, the method further comprising delaying **(18)** the release of bearers listed in the E-RAB to be released list.

According to some of the example embodiments, the delay may provide the source base station a chance to keep the bearers which the core network node was not able to switch for some reason.

6. The method of any of example embodiments 4-5, further comprising forwarding **(20)**, to the source base station, the E-RAB to be released list.

According to some of the example embodiments, this may be accomplished via a new X2 message.

7. The method of claim 6, wherein the E-RAB to be released list comprises at least one bearer which the core network node was not able to switch to the target base station in the selective handover procedure.

According to some of the example embodiments, this situation may arise when the sub-set of bearers were properly handed over between the target and source base stations. However, the core network node may not have been able to switch at least one bearer to a new path.

8. The method of example embodiment 7, further comprising receiving **(22)**, from the source base station, a response message, said response message comprising a decision as to which of the bearers that the source base station will keep established within itself.

According to some of the example embodiments, this decision may be communicated to the target base station via a new X2 message.

9. The method of example embodiment 8, further comprising determining **(24)** bearers the source base station does not keep (e.g., from the response message) and forwarding **(26)**, to the core network node, the response message comprising an identity of the determined bearers.

According to some of the example embodiments, the response message may be communicated to the core network via a new S1 message.

It should be appreciated that once the target base station receives the bearers to be released in the path switch acknowledgement message, the target base station may release the bearers. Specifically, according to some of the example embodiments, the target base station does not have to wait until the response is received from the source base station and it is the source base station that releases the bearers that it does not want to keep (not the target).

10. A target base station for providing a handover of at least a sub-set of bearers associated with a user equipment, the target base station comprising:
 - processing circuitry **(420)** configured to establish a connection for the sub-set of bearers associated with the user equipment via a selective handover procedure;
 - radio circuitry **(410)** configured to receive, from a source base station or a user equipment, a handover competition message for the sub-set of bearers associated with the user equipment; and
 - the radio circuitry **(410)** further configured to send, to a core network node, a path switch request, said path switch request comprising an information element providing an indication that a selective handover procedure was performed.

According to some of the example embodiments, the source base station may be functioning as either a booster or anchor node, while the target base station may also function as either a booster or anchor node. Thus, according to some of the example embodiments, the selective handover procedure may take place from an anchor (source) to a booster (target) node, from a booster (source) node to another booster (target) node, or from a booster (source) node to an anchor (target) node.
11. The target base station of example embodiment 10, wherein the path switch request further comprises a list of bearers which are still to be kept established with a source base station.

According to some of the example embodiments, since a selective handover procedure may be indicated in the path switch request, the core network node may know not to release bearers that are to be kept with the source base station.
12. The target base station of any of example embodiments 10-11, wherein the path switch request further comprises a list of bearers which are to be released.
13. The target base station of any of example embodiments 10-12, wherein the radio circuitry **(410)** is further configured to receive, from the core network node, a path switch request acknowledgement message.
14. The target base station of example embodiment 13, wherein the path switch request acknowledgement comprises an E-RAB to be released list, the processing circuitry **(420)** is further configured to delay the release of bearers listed in the E-RAB to be released list.

According to some of the example embodiments, the delay may provide the source base station a chance to keep the bearers which the core network node was not able to switch for some reason.

15. The target base station of any of example embodiments 13-14, wherein the radio circuitry **(410)** is further configured to send, to the source base station, the E-RAB to be released list.

According to some of the example embodiments, this may be accomplished via a new X2 message.

16. The target base station of claim 15, wherein the E-RAB to be released list comprises at least one bearer which the core network node was not able to switch to the target base station in the selective handover procedure.

According to some of the example embodiments, this situation may arise when the sub-set of bearers were properly handed over between the target and source base stations. However, the core network node may not have been able to switch at least one bearer to a new path.

17. The target base station of example embodiment 16, wherein the radio circuitry **(410)** is further configured to receive, from the source base station, a response message, said response message comprising a decision as to which of the bearers that the source base station will keep established within itself.

According to some of the example embodiments, this decision may be communicated to the target base station via a new X2 message.

18. The target base station of example embodiment 17, wherein the processing circuitry **(420)** is further configured to determine bearers the source base station does not keep (e.g., from the response message) and forward, to the core network node, the response message comprising an identity of the determined bearers.

According to some of the example embodiments, the response message may be communicated to the core network via a new S1 message.

It should be appreciated that once the target base station receives the bearers to be released in the path switch acknowledgement message, the target base station may release the bearers. Specifically, according to some of the example embodiments, the target base station does not have to wait until the response is received from the source base station and it is the source base station that releases the bearers that it does not want to keep (not the target).

19. The target base station of any of example embodiments 1-18, wherein the core network node is a MME, SGSN or a S4-SGSN.

20. A method, in a core network node, for providing a path switch or relocation of at least a sub-set of bearers associated with a user equipment, the method comprising:

receiving **(30)**, from a target base station, a path switch request for the sub-set of bearers associated with the user equipment, said path switch request comprising an information element providing an indication that a selective handover procedure was performed; and performing **(32)** bearer operations based on the information element.

21. The method of example embodiment 20, wherein the path switch request further comprises a list of bearers which are still to be kept established with a source base station.

According to some of the example embodiments, since a selective handover procedure may be indicated in the path switch request, the core network node may know not to release bearers that are to be kept with the source base station.

22. The method of any of example embodiments 20-21, wherein the path switch request further comprises a list of bearers which are to be released.

23. The method of any of example embodiments 20-22, wherein the performing **(32)** further comprises releasing **(34)** bearers which are not to be kept with the source base station or not to be switched to the target.

According to some of the example embodiments, the identity of the bearers which are not kept in the source base station may be provided in the path switch request.

24. The method of any of example embodiments 20-23, wherein the core network node is configured to avoid the release of bearers not listed in the path switch request message.

According to some of the example embodiments, the core network node may comprise different configurations for different source and target nodes. Thus, the core network node may treat a same message differently depending on the source and target node involved in the selective handover procedure.

25. The method of any of example embodiments 20-24, further comprising sending **(36)**, to a SGW or GGSN, a MODIFY BEARER REQUEST, said MODIFY BEARER REQUEST comprising a list of bearers which will remain with the source base station.

According to some of the example embodiments, the SGW or GGSN may keep associations of the bearers for which it was not able to switch the path to the target in order to give the source base station a chance to reclaim such bearers. In contrast, legacy systems delete associations in the SGW or GGSN for the bearers that the path switching has failed.

26. The method of example embodiment 25, further comprising receiving **(38)**, from the SGW or GGSN, a MODIFY BEARER RESPONSE, said MODIFY BEARER RESPONSE comprising a list of bearers which are marked for release.

According to some of the example embodiments, the core network node may keep associations of the bearers which were marked for release in order to give the source base station a chance to reclaim such bearers. In contrast, legacy systems delete associations in the core network for the bearers marked for release.

27. The method of example embodiment 25, further comprising sending **(40)**, to the target base station, a path switch request acknowledgement message.

28. The method of example embodiment 27, wherein the path switch request acknowledgement comprises an E-RAB to be released list.

According to some of the example embodiments, the target base station may release bearers listed in the E-RAB to be released list. According to some of the example embodiments, the E-RAB to be released list may be provided by the MODIFY BEARER RESPONSE.

29. A method, in a core network node, for path switching or relocation of at least a sub-set of bearers associated with a user equipment, the method comprising:

receiving **(42)**, from a target base station, a X2 message comprising an indication of at least one bearer that a source base station will keep an association with, said at least one bearer not being switched at the core network node;

releasing **(44)** bearers which the source base station will not keep an association with; and
sending **(46)**, to a SGW or GGSN, a communication message said communication message instructing the SGW or GGSN to keep the bearers that the source is willing to keep associations with and release the remaining ones among all the bearers of the UE that were not switched properly at the SGW or GGSN

According to some example embodiments, the X2 message may be a new message not yet comprised in the standard.

30. A core network node, for providing a path switch or relocation of at least a sub-set of bearers associated with a user equipment, the core network node comprising:

radio circuitry **(510)** configured to receive, from a target base station, a path switch request for the sub-set of bearers associated with the user equipment, said path switch request comprising an information element providing an indication that a selective handover procedure was performed; and

processing circuitry **(520)** configured to perform bearer operations based on the information element.

31. The core network node of example embodiment 30, wherein the path switch request further comprises a list of bearers which are still to be kept established with a source base station.

According to some of the example embodiments, since a selective handover procedure may be indicated in the path switch request, the core network node may know not to release bearers that are to be kept with the source base station.

32. The core network node of any of example embodiments 30-31, wherein the path switch request further comprises a list of bearers which are to be released.

33. The core network node of any of example embodiments 30-32, wherein the processing circuitry **(520)** is further configured to release bearers which are not to be kept with the source base station or not to be switched to the target.

According to some of the example embodiments, the identity of the bearers which are not kept in the source base station may be provided in the path switch request.

34. The core network node of any of example embodiments 30-33, wherein the core network node is configured to avoid the release of bearers not listed in the path switch request message.

According to some of the example embodiments, the core network node may comprise different configurations for different source and target nodes. Thus, the core network node may treat a same message differently depending on the source and target node involved in the selective handover procedure.

35. The core network node of any of example embodiments 30-34, wherein the radio circuitry **(510)** is further configured to send, to a SGW or GGSN, a MODIFY BEARER REQUEST, said MODIFY BEARER REQUEST comprising a list of bearers which will remain with the source base station.

According to some of the example embodiments, the SGW or GGSN may keep associations of the bearers for which it was not able to switch the path to the target in order to give the source base station a chance to reclaim such bearers. In contrast, legacy systems delete associations in the SGW or GGSN for the bearers that the path switching has failed.

36. The core network node of example embodiment 35, wherein the radio circuitry **(510)** is further configured to receive, from the SGW or GGSN, a MODIFY BEARER RESPONSE, said MODIFY BEARER RESPONSE comprising a list of bearers which are marked for release.

According to some of the example embodiments, the core network may keep associations of the bearers which were marked for release in order to give the source base station a chance to reclaim such bearers. In contrast, legacy systems delete associations in the MME for the bearers marked for release.

37. The core network node of example embodiment 36, wherein the radio circuitry **(510)** is further configured to send, to the target base station, a path switch request acknowledgement message.
38. The core network node of example embodiment 37, wherein the path switch request acknowledgement comprises an E-RAB to be released list.

According to some of the example embodiments, the target base station may release bearers listed in the E-RAB to be released list. According to some of the example embodiments, the E-RAB to be released list may be provided by the MODIFY BEARER RESPONSE.

39. The core network node of any of example embodiments 30-38, wherein the core network node is a MME, SGSN, or a S4-SGSN.
40. A core network node for path switching or relocation of at least a sub-set of bearers associated with a user equipment, the core network node comprising:
 - radio circuitry **(510)** configured to receive, from a target base station, a X2 message comprising an indication of at least one bearer that a source base station will keep an association with, said at least one bearer not being switched at the core network node;
 - processing circuitry **(520)** configured to release bearers which the source base station will not keep an association with; and
 - the radio circuitry **(510)** further configured to send, to a SGW or GGSN, a communication message said communication message instructing the SGW or GGSN to keep the bearers that the source is willing to keep associations with and release the remaining ones among all the bearers of the UE that were not properly switched at the SGW or GGSN

According to some example embodiments, the X2 message may be a new message not yet comprised in the standard.

41. The core network node of example embodiment 40, wherein the core network node is a MME, SGSN, or a S4-SGSN.

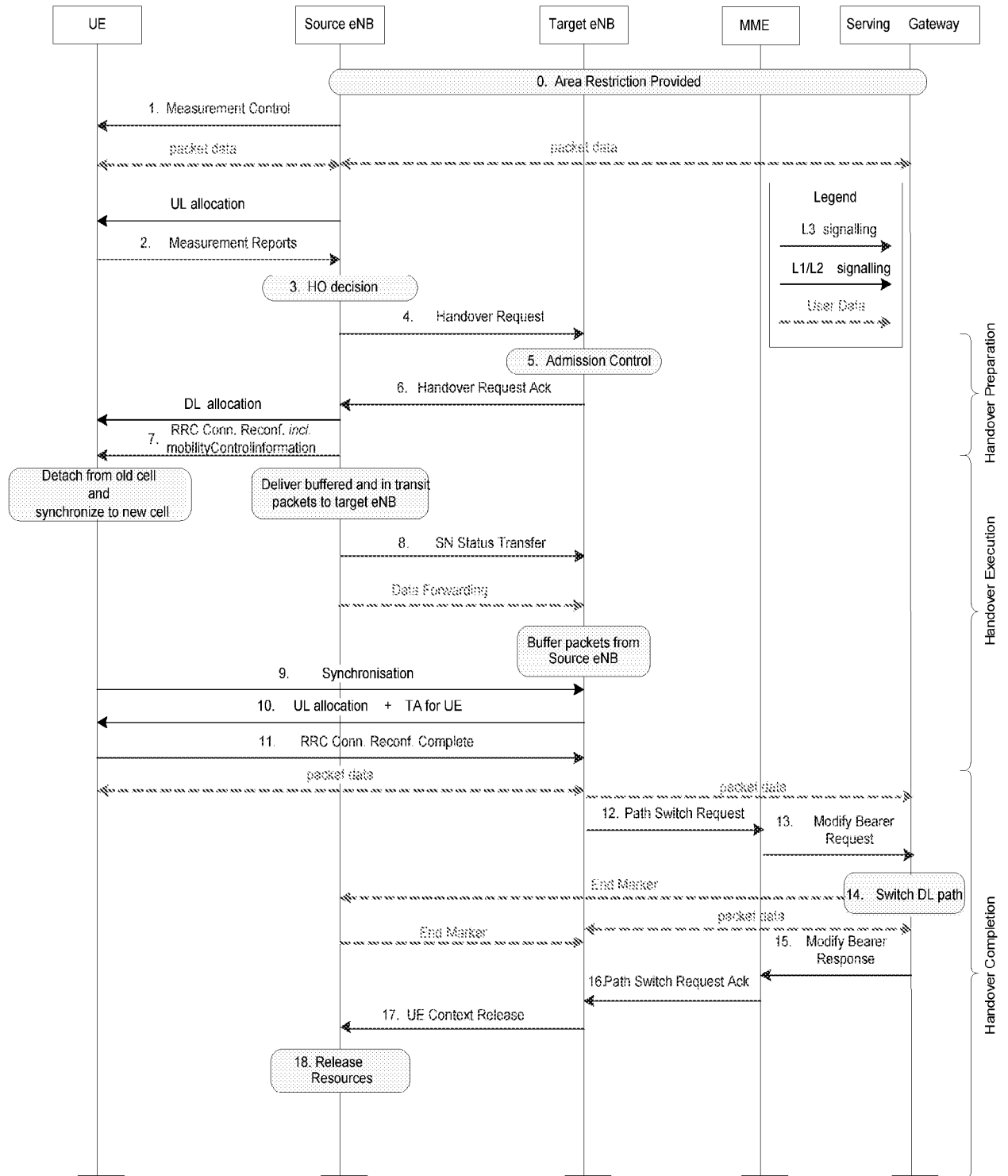


Figure 14: X2 Handover in LTE

4 Brief summary of some of the example embodiments

According to some of the example embodiments, an optimized approach to handover that takes advantage of multiple connectivity of a UE to several eNBs, where the handover can be triggered and/or executed at a bearer level rather than the current UE level approach that is used in LTE is proposed. Different handover triggering conditions can be set, and based on these conditions as well as other factors such as load and UE/network buffer conditions, a selective handover of only a subset of the UE bearers is performed.

5 Detailed description of the example embodiments

5.1 One non-limiting example implementation

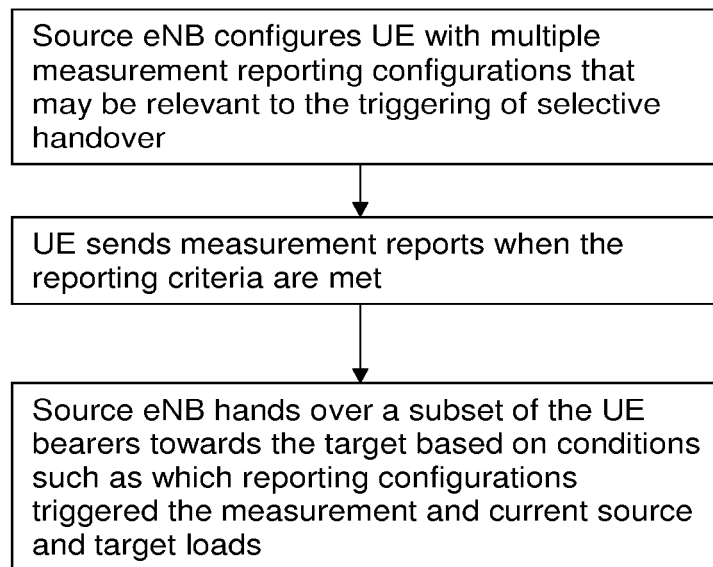


Figure 15: One non-limiting example implementation

One non-limiting example of some of the embodiments is shown in Figure 15. The details of the some of the example embodiments are given below. For the sake of brevity, the descriptions below treat only the case of dual connectivity with two eNBs, but the ideas are equally applicable for the case where the UE is connected to more than two eNBs at the same time. Also, unless otherwise specified, by a bearer it is meant a data radio bearer.

It should be appreciated that many example embodiments are provided below. These example embodiments may be utilized in any combination with one another.

According to some of the example embodiments, a source eNB may decide to initiate a selective handover of a subset of the bearers of a UE towards a target eNB. Several mechanisms can be employed by the source eNB to decide which bearers to choose for the selective handover.

According to some of the example embodiments, the source eNB has a static mapping that specifies which type of bearers should be comprised in the selective handover. Several mapping rules could be used, such as:

- only non-GBR bearers, or
- only GBR bearers , or
- only GBR bearers with MBR above or below a certain level, or
- only GBR bearers with GBR above or below a certain level, or
- only bearers that belong to a certain (set) of QCI(s), etc.

For example, if the deployment scenario is that the macro has good coverage and a pico node is deployed in another carrier frequency for high data rate boosting, the static mapping rule can be to choose only the high data rate bearers for selective handover towards the pico node.

According to some of the example embodiments, the source eNB configures the UE with multiple measurement reporting configurations, and depending on which report gets triggered, decide the bearers to be comprised in the selective handover. As a simple example, the source eNB can configure two measurement configurations based on the A3 Event, and set different threshold values for each. If the first report gets triggered, the eNB may choose certain bearers (e.g. non GBR bearers) for the selective handover, and similarly, if the second report gets triggered, the eNB may choose other kind of bearers (e.g. GBR bearers) for the selective handover. Note that this is just an example, and other events can be used to select different bearers.

According to some of the example embodiments, the source eNB can decide which bearers to handover based on the buffer levels of the different bearers. For example, only bearers that have buffers filled above or below a certain level are chosen for selective handover.

According to some of the example embodiments, new triggering events are defined specifically suitable for selective handover. For example, an A7 event may be defined that is triggered only when the UE buffer rises above a specified threshold level for certain kind of bearers and the radio conditions with the serving cell becomes worse than a specified threshold.

According to some of the example embodiments, the source eNB can decide which bearers to handover based on the load situation at the source and target eNBs. For example, more bearers could be comprised in the selective handover if the target eNB is unloaded. Legacy X2 RESOURCE STATUS UPDATE messages could be employed to exchange the load status information between the source and target eNBs.

According to some of the example embodiments, a source eNB may configure a lower threshold value to trigger early measurements and when these measurements are received, the serving eNB may decide to initiate selective handover to the target eNB but with an empty bearer list (i.e. not handing over anything). The purpose of this “empty handover” may be to allow synchronization of the UE to the target eNB cell. In case such “empty” selective handover is carried out and the UE is synchronized to the target eNB cell, it will be possible to transmit future mobility signaling from both serving and target cell.

According to some of the example embodiments, a source eNB may configure a higher threshold value in a measurement configurations, and when such measurement is triggered, the serving eNB initiates a full (legacy) handover towards the target eNB.

Note that the selection mechanisms described above can be used together.

According to some of the example embodiments, a source eNB may decide to initiate the handover of the signaling radio bearers towards the target eNB. After the handover the target becomes the anchor node (the termination point for the control plane) and the source becomes the booster node. The source eNB can also choose to comprised some data radio bearers in this handover request. That is, after the handover, the source might handle some data radio bearers of the UE, while the target will handle all the signaling radio bearers and the other data radio bearers.

During such handover procedure and in case the user plane (i.e. PDCP or PDCP and RLC) are terminated in the anchor node, the mechanism consists of switching all user plane bearers traffic from the core network to the new anchor node. Namely, in an anchor node terminated user plane scenario, a handover that implies a change in the anchor node also implies switching user plane bearers traffic termination from old anchor node to new anchor node. In this procedure, the PATH SWITCH REQUEST message towards the core network will indicate switching of all bearers towards the new anchor node, while (in case source and target cell do not reside in the same node) the X2: HANDOVER REQUEST message will indicate to the new anchor node (target node) which bearer traffic shall be transmitted over the air at the new anchor node cell and which shall be transmitted at the new booster node cell.

According to some of the example embodiments, the target eNB does not belong to the same soft cell as the source eNB (i.e. target eNB an independent eNB such as a neighbor macro eNB or a pico eNB operating as a standalone cell). That is, for the concerned UE, the target eNB will play the role of the booster eNB.

In legacy handover, the source eNB prepares the target eNB using the HANDOVER REQUEST message over X2, as shown in **Figure 14**. The contents of this message are shown in Table 1. This X2AP message comprised a transparent container comprising the RRC context from the source. For selective handover, the same principles can be reused, but the message content has to be modified, since the RRC control context remains in the source eNB, and only a set of E-RABs are requested to be handed over.

Table 1: X2 HANDOVER REQUEST message

IE/Group Name	Presence
Message Type	M
Old eNB UE X2AP ID	M
Cause	M
Target Cell ID	M
GUMMEI	M
UE Context Information	
>MME UE S1AP ID	M
>UE Security Capabilities	M
>AS Security Information	M
>UE Aggregate Maximum Bit Rate	M
>Subscriber Profile ID for RAT/Frequency priority	O
>E-RABs To Be Setup List	
>>E-RABs To Be Setup Item	
>>>E-RAB ID	M
>>>E-RAB Level QoS Parameters	M
>>>DL Forwarding	O
>>>UL GTP Tunnel Endpoint	M
>RRC Context	M
>Handover Restriction List	O
>Location Reporting Information	O
>Management Based MDT Allowed	O
UE History Information	M
Trace Activation	O
SRVCC Operation Possible	O
CSG Membership Status	O

According to some of the example embodiments, the target eNB is informed that a given handover is a selective handover rather than a legacy handover (i.e. full handover where all the bearers of the UE have to be handed over) during handover preparation signaling. In case the target eNB receives multiple selective handover requests concerning the same UE from the same source eNB, it shouldn't be interpreted as an error, but rather as a request to selectively hand over even more bearers of the UE towards the target.

According to some of the example embodiments, if the anchor connection is lost while the UE has a booster link active, the booster eNB can assume the role of the anchor (i.e. terminate the control plane and SRBs). The new anchor (the old booster) can use the MME UE S1AP ID that was received during the handover request to recover the context of the UE from the MME and hence be able to re-establish any radio bearers that were being served via the previous anchor.

The legacy X2 HANDOVER REQUEST message already comprises a list of E-RABs to be setup. For the case of selective handover, this list also can be used to cover the data radio bearers that the anchor wants to handover to the booster cell. The rest of the E-RABs will remain at the source eNB. So, this list can be used as is. However, if a partial list of E-RABs is comprised in the X2: HANDOVER REQUEST message the target is assumed to send a PATH SWITCH REQUEST message to the MME indicating switching of bearers listed in X2: HANDOVER REQUEST message. Current specifications in TS 36.413 specify that

“If the E-RAB To Be Switched in Downlink List IE in the PATH SWITCH REQUEST message does not comprise all E-RABs previously comprised in the UE Context, the MME shall consider the non included E-RABs as implicitly released by the eNB.”

The above means that according to current specifications the bearers not listed in PATH SWITCH REQUEST and assigned to the UE will be automatically dropped by the MME. Therefore, two solution can be envisioned to prevent such E-RAB termination:

- 1) The PATH SWITCH REQUEST message shall be enhanced with a new IE indicating that a selective handover is ongoing and the non-listed E-RABs shall not be dropped.
- 2) The MME shall be configured (e.g. via the OAM system) so to avoid E-RAB terminations for the E-RABs not listed in the PATH SWITCH REQUEST message. The altter decision could be taken either unconditionally or depending on source node identity, which can be derived by the *Source MME UE S1AP ID* IE and *Source MME GUMMEI* IE in PATH SWITCH REQUEST message.

An example of how the PATH SWITCH REQUEST message IEs can be enhanced is shown in Table 1a, where a new IE named *Selective Handover Indicator* IE has been added as an example of how selective handovers could be flagged to the MME..

IE/Group Name	Presence	Range	Semantics description	Criticality	Assigned Criticality
Message Type	M			YES	reject
eNB UE S1AP ID	M			YES	reject
E-RAB To Be Switched in Downlink List		1		YES	reject
>E-RABs Switched in Downlink Item IEs		1 to <maxnoof E-RABs>		EACH	reject
>>E-RAB ID	M			-	
>>Transport layer address	M			-	
>>GTP-TEID	M		To deliver DL PDUs	-	
Source MME UE S1AP ID	M			YES	reject
E-UTRAN CGI	M			YES	ignore
TAI	M			YES	ignore
UE Security Capabilities	M			YES	ignore
CSG Id	O			YES	ignore
Cell Access Mode	O			YES	ignore
Source MME GUMMEI	O			YES	ignore
Selective Handover Indicator	O	ENUMERATED (true, ...)	This IE indicates to MME that the handover is selective. IT helps MME to decide whether to maintain bearers not listed in the E-RABs To Be Switched In Downlink List	YES	ignore

In legacy LTE, a historical information of the UEs mobility is maintained at the eNB and propagated to a target eNB when handover is performed via the X2 HANDOVER REQUEST message in an IE called UE History Information. This IE comprises a list of up to the last 16 cells the UE has visited, along with the cell type and the time the UE stayed in the corresponding cell. The UE history information is useful for optimizations such as ping pong handover detection, and estimation of UE mobility state which can be further used to scale speed dependent handover triggering parameters such as TTT. With multiple connectivity, as the UE can be connected to multiple cells at the same time, the use of UE history has to be adapted accordingly.

According to some of the example embodiments, selective handovers are treated the same way as in legacy LTE full handovers, and the UE history information is updated accordingly. For example, if a UE goes from IDLE to CONNECTED mode in cell A at time t1, selectively handed over to cell B at time t2, removed from cell B back to cell A at time t3 (i.e. all the bearers that were connected to B now associated with A again) and fully handed over to cell C at time t4, the UE history information received by the node supporting Cell C during handover preparation towards Cell C will comprise the entries shown in Table 2

Table 2: UE history, selective handovers treated as full handovers

Cell ID	Cell Type	Time UE stayed in a cell
A	Type 1	t2-t1

B	Type 2	t3-t2
A	Type 1	t4-t3

According to some of the example embodiments, the selective handovers are treated also the same way, but the time the UE stayed in a cell will be measured as the duration between the first time the UE is handed over to the cell (either fully or selectively) and the time it completely leaves that cell (i.e. no bearers with the concerned cell and also UE context released) between full handovers. For the same example as above, the UE history information in this case will be like the entries shown in Table 3:

Table 3: UE history, selective handovers treated as full handovers, but source eNB time kept active

Cell ID	Cell Type	Time UE stayed in a cell
A	Type 1	t4-t1
B	Type 2	t3-t2

According to some of the example embodiments, selective handovers are not registered in the UE history information. For the same example as above, the UE history information in this case will be like the entries shown in Table 4

Table 4: UE history, selective handovers ignored in the UE history.

Cell ID	Cell Type	Time UE stayed in a cell
A	Type 1	t4-t1

The advantage of these three ways of updating the UE history information is that they are backward compatible. However, the information regarding multiple connectivity is lost. In order to capture this, the UE history information IE has to be modified.

According to some of the example embodiments, a timestamp field is added in the UE history information IE that tells exactly when the UE was handed over to a cell. So for the same example as above, the UE history information will be like the entries shown in Table 5. Thus by looking at the timestamp and the duration, cell C can find out that the UE was connected to both cells during the time duration t3-t2.

Table 5: UE history, selective handovers implicitly indicated via time-stamping.

Cell ID	Cell Type	Time UE started connection in a cell	Time UE stayed in a cell
A	Type 1	t1	t4-t1
B	Type 2	t2	t3-t2

According to some of the example embodiments, a handover type field is added to the UE history to indicate selective handovers. For the same example as above, the UE history information will look like Table 6.

Table 6: UE history, selective handovers indicated explicitly.

Cell ID	Cell Type	Handover type	Time UE stayed in a cell
A	Type 1	Selective	t2-t1
B	Type 2	Selective	t3-t2
A	Type 1	Selective	t4-t3

According to some of the example embodiments, an additional IE is comprised in the UE history information which indicates the anchor/booster roles played by the eNBs for that particular UE. This additional information can be useful during recovery from failures. For the same example as above, the UE history information will look like Table 7

Table 7: UE history, selective handovers and eNB roles indicated explicitly.

Cell ID	Cell Type	Handover type	Cell Role	Time UE stayed in a cell
A	Type 1	Selective	Anchor	t2-t1
B	Type 2	Selective	Booster	t3-t2
A	Type 1	Selective	Anchor	t4-t3

The other IEs in the legacy X2 HANDOVER REQUEST message (i.e. Message Type, Old eNB UE X2AP ID, Cause, Target Cell ID, GUMMEI, Trace Activation, SRVCC Operation Possible and CSG Membership Status) can be used as is for selective handovers.

In legacy handover, as shown in when the target eNB receives a HANDOVER REQUEST message, it performs admission control and if it can admit one or more of the data radio bearers comprised in the request, it sends a HANDOVER REQUEST ACKNOWLEDGE message over X2 towards the source eNB, as shown in Figure 14. The contents of this message are shown in

Table 8. The bearers that are not admitted are comprised in the E-RABs Not Admitted List IE. As can be seen from the table, all the IEs in this message can be used as is for supporting selective handovers.

Table 8: X2 HANDOVER REQUEST ACKNOWLEDGE message

IE/Group Name	Presence
Message Type	M
Old eNB UE X2AP ID	M
New eNB UE X2AP ID	M
E-RABs Admitted List	
> E-RABs Admitted Item	
>> E-RAB ID	M
>> UL GTP Tunnel Endpoint	O
>> DL GTP Tunnel Endpoint	O
E-RABs Not Admitted List	O
Target eNB To Source eNB Transparent Container	M
Criticality Diagnostics	O

According to some of the example embodiments, when a HANDOVER REQUEST ACKNOWLEDGE message that comprises some entries in the E-RABs Not Admitted List is received, the source eNB decides to keep those bearers with itself and hand over only the ones listed in the E-RABs Admitted List.

According to some of the example embodiments, when a HANDOVER REQUEST ACKNOWLEDGE message that comprises some entries in the E-RABs Not Admitted List is received, the source eNB decides to cancel the handover. The source can communicate this to the target using the X2 HANDOVER CANCEL message, with a cause value of “partial handover”.

According to some of the example embodiments, when a HANDOVER REQUEST ACKNOWLEDGE message that comprises some entries in the E-RABs Not Admitted List is received, the source eNB decides to drop those bearers and hand over only the ones listed in the E-RABs Admitted List.

According to some of the example embodiments, the source eNB sends out a full handover request (legacy HO) and when it gets a HANDOVER REQUEST ACKNOWLEDGE where there are some entries in the E-RABs Not Admitted List, will change the full handover request to selective handover (if it knows that the target accepts selective handovers). This can be done in several ways, for example:

- The source eNB explicitly cancels the handover request by sending an X2 HANDOVER CANCEL command with a cause value of “partial Handover” towards the target followed by a selective HANDOVER REQUEST that comprises only the bearers that the target was able to admit in the handover that was just cancelled.
- The source implicitly notifies the change of the handover from full to selective by sending an X2 HANDOVER REQUEST message.

- The source eNB sends a new X2 message (e.g. HANDOVER REQUEST UPDATE) towards the target that tells it to change the previous handover request from full to selective.

with the selective handover IE set and with the list of only the bearers that the target was able to admit.

According to some of the example embodiments, the target eNB, when it gets an X2 HANDOVER REQUEST for a UE that it has already received a handover request and prepared for, and that the new request is a selective handover request, or when it gets a HANDOVER REQUEST UPDATE message, will update the handover as selective (i.e. it will not try to setup the SRBs when the UE connects to it later on) and resends an X2 HANDOVER REQUEST ACKNOWLEDGE message. For the sake of consistency, the sender can comprise the list of bearers to be admitted in the X2 HANDOVER REQUEST and HANDOVER REQUEST UPDATE messages, but this is not required, as the target already has this information from the previous request.

According to some of the example embodiments, when an X2 HANDOVER REQUEST ACKNOWLEDGE message, the source eNB decides to handover only a sub set of the admitted bearers and keep the rest with itself. This can be communicated in several ways as above, i.e. explicitly canceling the handover followed by a new request, sending a request that will invalidate the previous one, or sending a new X2 message (e.g. HANDOVER REQUEST UPDATE).

According to some of the example embodiments, the target eNB, when it gets an X2 HANDOVER REQUEST for a UE that has already received a handover request and prepared for (either full or selective handover), and that the new request is a selective handover request, or when it gets a HANDOVER REQUEST UPDATE message, will update the handover as selective (if the previous one was not selective and in that case it will not try to setup the SRBs when the UE connects to it later on) and resends an X2 HANDOVER REQUEST ACKNOWLEDGE message. In this case the X2 HANDOVER REQUEST and HANDOVER REQUEST UPDATE messages comprise the bearers to be admitted (as they are different from the ones that were listed in the original admitted list). The target also releases any resources that it might have reserved for the bearers not comprised in this updated list.

According to some of the example embodiments, when the source eNB selectively hands over the HANDOVER REQUEST ACKNOWLEDGE message, it keeps the mapping of the New eNB UE X2AP ID and Old eNB UE X2AP ID, so that if a HANDOVER REQUEST is received later on from the target eNB that has the same Old eNB UE X2AP ID as the New eNB UE X2AP ID saved in this mapping, it knows that it is a UE that is returning towards the anchor after selectively handed over for some time.

According to some of the example embodiments, the target eNB keeps, after accepting a selective handover, the mapping of the New eNB UE X2AP ID and Old eNB UE X2AP ID.

According to some of the example embodiments, an eNB acting like a booster, to which some of the UE bearers have been selectively handed over to from the anchor eNB, can later on perform selective handover of the UE to another booster eNB. This can be performed in several ways, for example:

- The old booster hands over the bearers back to the anchor, with an indication (e.g. via a new IE in the X2 HANDOVER REQUEST message) that recommends the selective handover of these bearers to the new booster. The anchor can use recommendation and may handover the bearers to the new booster or decide to keep it with itself or drop them.
- The old booster sends an X2 HANDOVER REQUEST message towards the new booster, but with an additional indication about the anchor node responsible for the UE (e.g. via a new IE). The new booster then sends the HANDOVER REQUEST ACKNOWLEDGE message towards the anchor node. The anchor can implicitly assume the booster has been changed when it receives this (e.g. the old booster can use the Old eNB X2 AP ID that it has originally received from the anchor as the Old eNB X2 AP ID in the HANDOVER REQUEST message it is sending instead of the eNB X2 AP ID that it is using, i.e. the one that was indicated in New eNB X2 AP ID during the handover between the anchor and the old booster).
- Similar to the above case, but the booster also sends a new X2 message to the anchor indicating that it has initiated selective handover towards the new booster immediately after sending the request to the new booster. As such the booster relocation is explicitly known at the anchor, and the anchor knows the success of it with the reception of HANDOVER REQUEST ACKNOWLEDGE from the new booster.
- The old booster sends an X2 HANDOVER REQUEST message towards the new booster, waits to get the X2 HANDOVER REQUEST ACKNOWLEDGE message, and forwards this towards the anchor in a transparent container comprised in a new X2 message (e.g. X2 BOOSTER RELOCATION).

According to some of the example embodiments, when the anchor eNB finds out that a booster relocation has been performed, it updates the mapping of the Old eNB UE X2 AP ID to the New eNB UE X2 AP ID, based on the New eNB UE that is being used in the new booster.

An LTE system has been assumed throughout the discussion the example embodiments. However, most of the ideas discussed above can become readily applicable to mobile broadband systems such as High Speed Packet Access (HSPA) or any other wireless system.

6 Example advantages of the example embodiments

The ideas discussed in relation to the example embodiments makes it possible to perform handovers selectively between a source and a target eNB, thereby creating more system flexibility than the legacy way of performing handover where a UE is completely handed over to the target. Some advantages of this are:

- Possibility to keep all the UE bearers ongoing as the bearers that the target was not able to admit can be kept at the source
- Possibility to trigger handover at a bearers level rather than at UE level. For example, the source eNB can keep the bearers that can't tolerate discontinuity such as VoIP services with itself until the radio conditions of the source are at much lower quality than the target, while bearers that are very capacity hungry but more tolerant to interruptions such as file download can be handed over to the target even if the radio conditions at the source are not that bad.

- Possibility to maintain control plane at one eNB, while sharing the data load at several eNBs. This opens several opportunities such as network sharing. For example, several operators can share the pico nodes for data bearers, while maintaining the signaling radio bearers only at their macros.
- Control plane diversity, such as sending of handover command from the source and/or targets or sending of the measurement report towards targets becomes rather straightforward with multiple connectivity.
- RLF on the booster or anchor node can be recovered faster. Booster recovery is straightforward as the UE context resides at the anchor, and anchor recovery also becomes fast as the booster can fetch the context easily from the network.

Most of the ideas discussed in relation to the example embodiments require specification changes and as such infringement of them can be easily detected.

7 Figures

7.1 Example node configurations

The following example nodes may be configured to perform the example operations discussed herein.

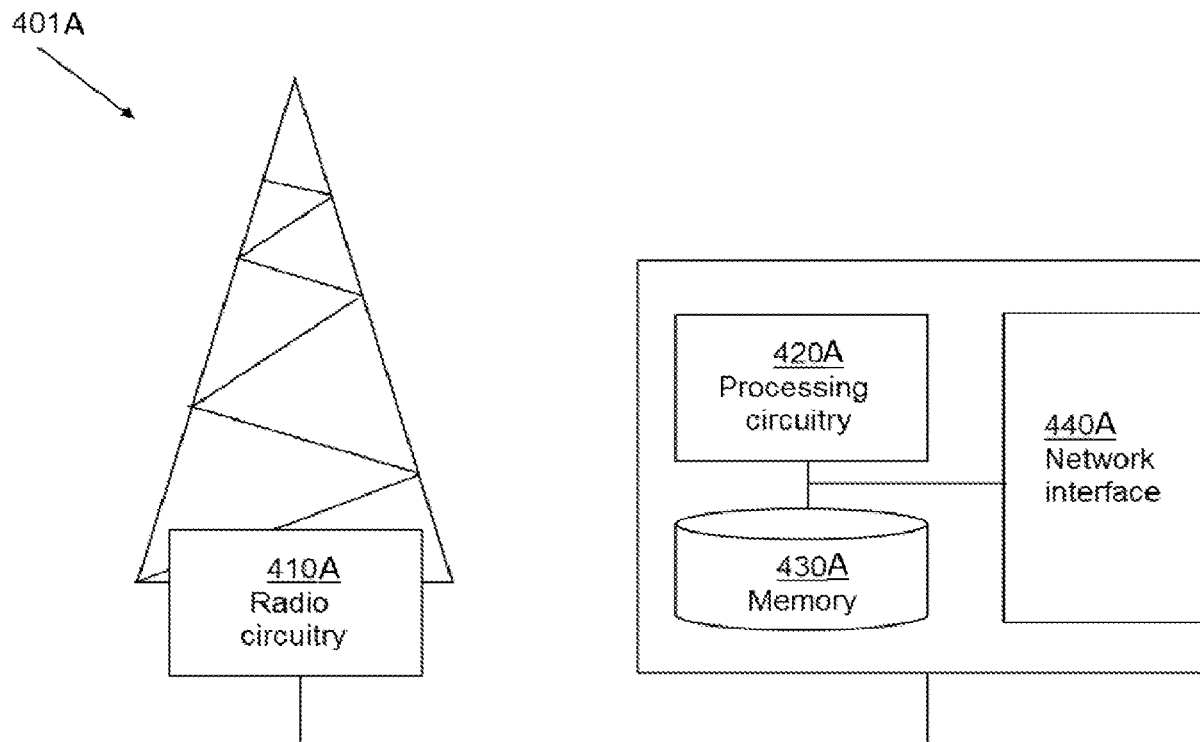


Figure 16 – Example configuration of a source base station

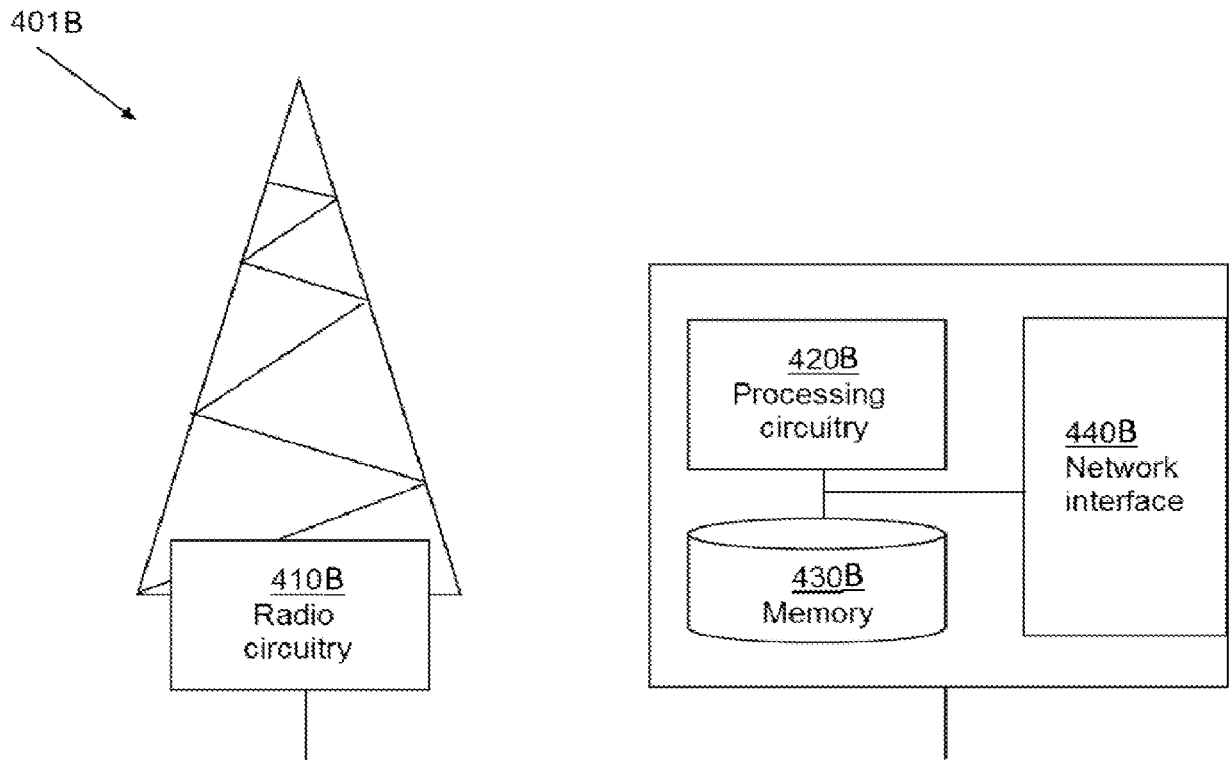


Figure 17 – Example configuration of a target base station

The example embodiments presented herein may be utilized in a wireless network, which may further comprise a source and target base station 401A and 401B, as illustrated in Figures 16 and 17, respectively. It should be appreciated that the examples provided in Figures 16 and 17 are shown merely as non-limiting examples.

As shown in Figure 16, the example source base station 401A may comprise processing circuitry 420A, a memory 430A, radio circuitry 410A, and at least one antenna. The processing circuitry 420A may comprise RF circuitry and baseband processing circuitry (not shown). In particular embodiments, some or all of the functionality described above as being provided by a mobile base station, a base station controller, a relay node, a NodeB, an enhanced NodeB, and/or any other type of mobile communications node may be provided by the processing circuitry 420A executing instructions stored on a computer-readable medium, such as the memory 430A shown in Figure 16.

Alternative embodiments of the source base station 401A may comprise additional components responsible for providing additional functionality, comprising any of the functionality identified above and/or any functionality necessary to support the solution described above. In other example embodiments, a network node may be not equipped with a radio interface or radio circuitry 410A.

It should also be appreciated that the processing circuitry (or any other hardware and/or software unit configured to execute operations and/or commands) of the source base station 401A illustrated in Figure 16 may be configured to configure to provide a selective handover procedure.

As shown in Figure 17, the example target base station 401B may comprise processing circuitry 420B, a memory 430B, radio circuitry 410B, and at least one antenna. The processing circuitry 420B may comprise RF circuitry and baseband processing circuitry (not shown). In particular embodiments, some or all of the functionality described above as being provided by a mobile base station, a base station controller, a relay node, a NodeB, an enhanced NodeB, and/or any other type of mobile communications node may be provided by the processing circuitry 420B executing instructions stored on a computer-readable medium, such as the memory 430B shown in Figure 17.

Alternative embodiments of the target base station 401B may comprise additional components responsible for providing additional functionality, comprising any of the functionality identified above and/or any functionality necessary to support the solution described above. In other example embodiments, a network node may be not equipped with a radio interface or radio circuitry 410B.

According to some of the example embodiments, the source base station may be functioning as either a booster or anchor node, while the target base station may also function as either a booster or anchor node. Thus, according to some of the example embodiments, the selective handover procedure may take place from an anchor (source) to a booster (target) node, from a booster (source) node to another booster (target) node, or from a booster (source) node to an anchor (target) node.

7.2 Flow diagrams

It should be appreciated that the terms ‘source base station’ and ‘target base station’ have been used to describe the example embodiments herein. It should be appreciated that the source and target in general may be thought of as cells. However, it is the base stations which send the messages described herein on behalf of their respective cells.

Figure 18 is a flow diagram depicting example operations which may be taken by the source base station 401A of Figure 16 in the providing a handover of at least a sub-set of bearers associated with a user equipment. It should also be appreciated that Figure 18 comprises some operations which are illustrated with a darker border and some operations which are illustrated with a lighter border. The operations which are comprised in a darker border are operations which are comprised in the broadest example embodiment. The operations which are comprised in a lighter border are example embodiments which may be comprised in, or a part of, or are further operations which may be taken in addition to the operations of the boarder example embodiments. It should be appreciated that these operations need not be performed in order. Furthermore, it should be appreciated that not all of the operations need to be performed. The example operations may be performed in any order and in any combination.

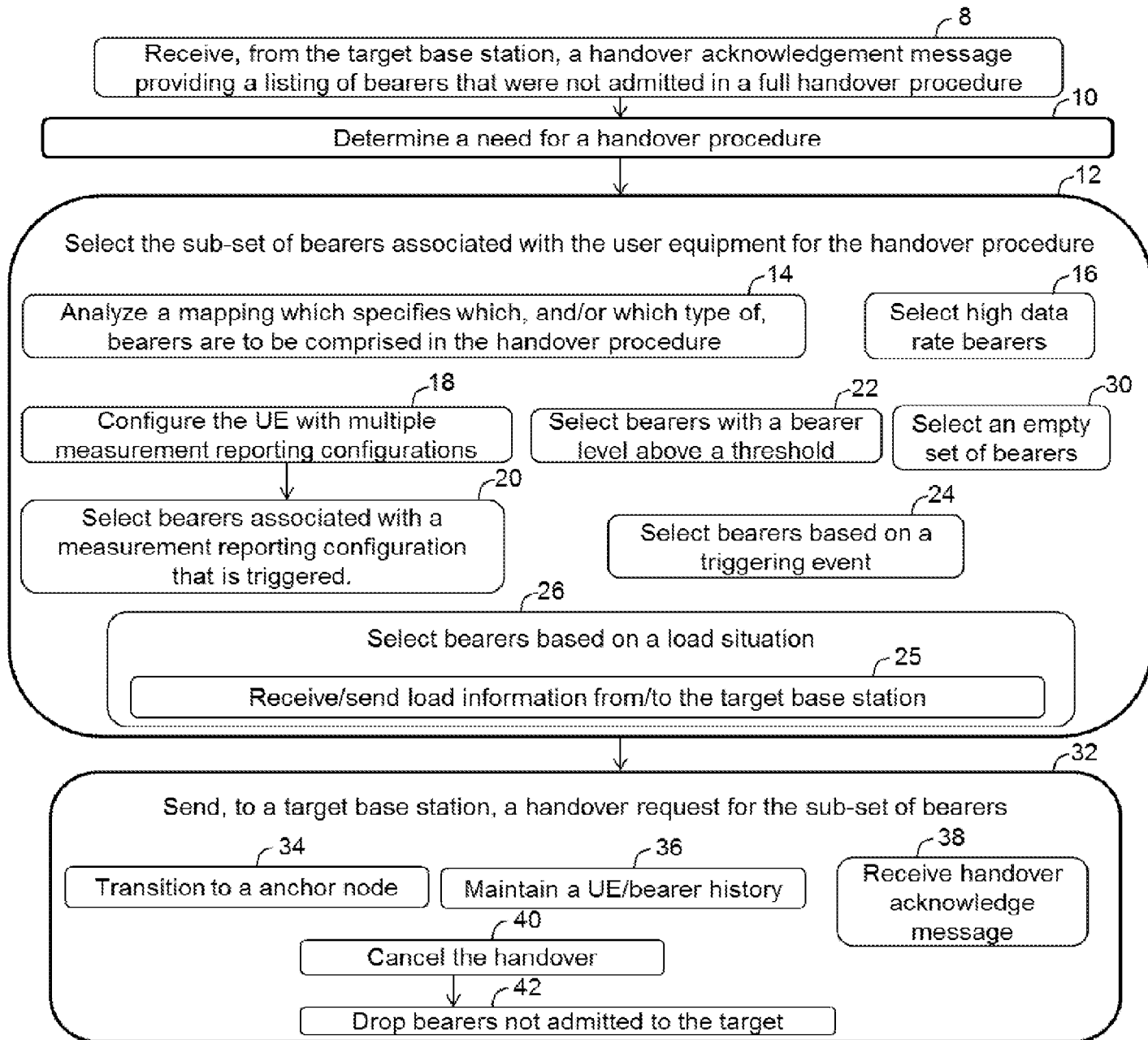


Figure 18 – flow diagram of example operations of a source base station

Figure 19 is a flow diagram depicting example operations which may be taken by the target base station 401B of Figure 17 in the providing a handover of at least a sub-set of bearers associated with a user equipment. It should also be appreciated that Figure 19 comprises some operations which are illustrated with a darker border and some operations which are illustrated with a lighter border. The operations which are comprised in a darker border are operations which are comprised in the broadest example embodiment. The operations which are comprised in a lighter border are example embodiments which may be comprised in, or a part of, or are further operations which may be taken in addition to the operations of the boarder example embodiments. It should be appreciated that these operations need not be performed in order. Furthermore, it should be appreciated that not all of the operations need to be performed. The example operations may be performed in any order and in any combination.

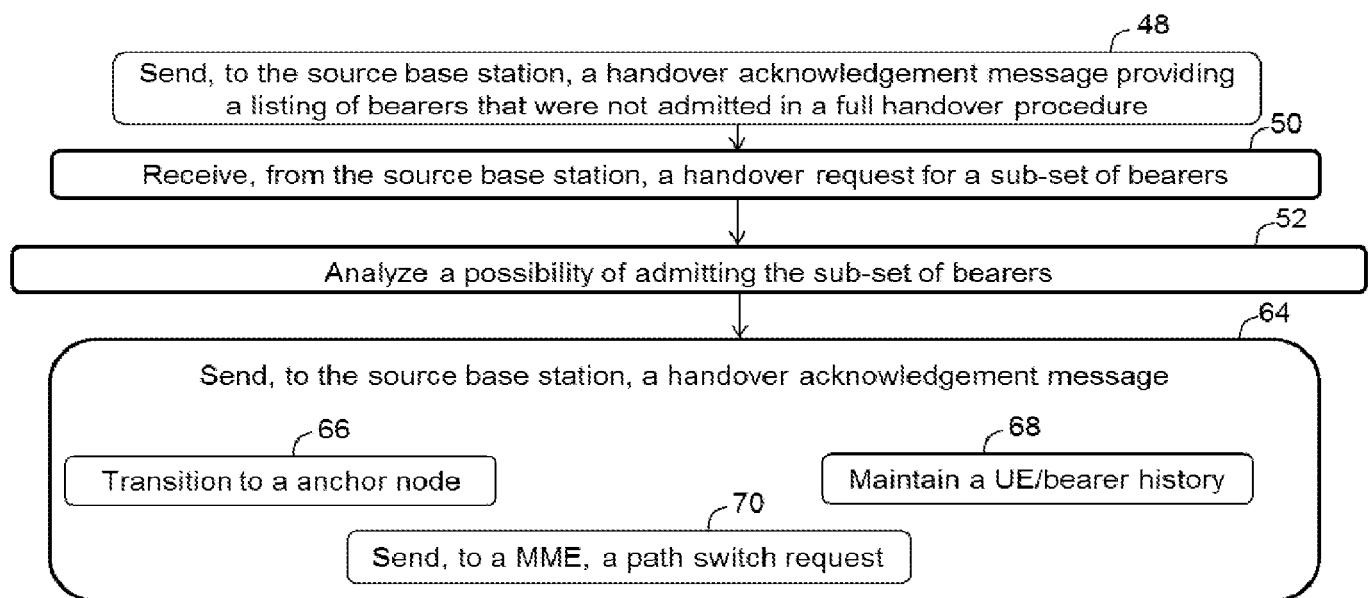


Figure 19 – flow diagram of example operations of a target base station

8 Conclusion

It should be noted that although terminology from 3GPP LTE has been used herein to explain the example embodiments, this should not be seen as limiting the scope of the example embodiments to only the aforementioned system. Other wireless systems, comprising WCDMA, WiMax, UMB, WiFi and GSM, may also benefit from the example embodiments disclosed herein.

The description of the example embodiments provided herein have been presented for purposes of illustration. The description is not intended to be exhaustive or to limit example embodiments to the precise form disclosed, and modifications and variations are possible in light of the above teachings or may be acquired from practice of various alternatives to the provided embodiments. The examples discussed herein were chosen and described in order to explain the principles and the nature of various example embodiments and its practical application to enable one skilled in the art to

utilize the example embodiments in various manners and with various modifications as are suited to the particular use contemplated. The features of the embodiments described herein may be combined in all possible combinations of methods, apparatus, modules, systems, and computer program products. It should be appreciated that the example embodiments presented herein may be practiced in any combination with each other.

It should be noted that the word “comprising” does not necessarily exclude the presence of other elements or steps than those listed and the words “a” or “an” preceding an element do not exclude the presence of a plurality of such elements. It should further be noted that any reference signs do not limit the scope of the claims, that the example embodiments may be implemented at least in part by means of both hardware and software, and that several “means”, “units” or “devices” may be represented by the same item of hardware.

Also note that terminology such as user equipment should be considered as non-limiting. A device or user equipment as the term is used herein, is to be broadly interpreted to comprise a radiotelephone having ability for Internet/intranet access, web browser, organizer, calendar, a camera (e.g., video and/or still image camera), a sound recorder (e.g., a microphone), and/or global positioning system (GPS) receiver; a personal communications system (PCS) user equipment that may combine a cellular radiotelephone with data processing; a personal digital assistant (PDA) that can comprise a radiotelephone or wireless communication system; a laptop; a camera (e.g., video and/or still image camera) having communication ability; and any other computation or communication device capable of transceiving, such as a personal computer, a home entertainment system, a television, etc. It should be appreciated that the term user equipment may also comprise any number of connected devices.

The various example embodiments described herein are described in the general context of method steps or processes, which may be implemented in one aspect by a computer program product, embodied in a computer-readable medium, comprising computer-executable instructions, such as program code, executed by computers in networked environments. A computer-readable medium may comprise removable and non-removable storage devices comprising, but not limited to, Read Only Memory (ROM), Random Access Memory (RAM), compact discs (CDs), digital versatile discs (DVD), etc. Generally, program modules may comprise routines, programs, objects, components, data structures, etc. that perform particular tasks or implement particular abstract data types. Computer-executable instructions, associated data structures, and program modules represent examples of program code for executing steps of the methods disclosed herein. The particular sequence of such executable instructions or associated data structures represents examples of corresponding acts for implementing the functions described in such steps or processes.

In the drawings and specification, there have been disclosed exemplary embodiments. However, many variations and modifications can be made to these embodiments. Accordingly, although specific terms are employed, they are used in a generic and descriptive sense only and not for purposes of limitation, the scope of the embodiments being defined by the following summary of example embodiments.

9 Abbreviations

3GPP	3 rd Generation Partnership Project
AMBR	Aggregate Maximum Bit Rate
AP	Application Protocol
ARP	Allocation and Retention Priority
ARQ	Automatic Repeat reQuest
BCH	Broadcast Channel
CIO	Cell Individual Offset
CN	Core Network
CRS	Cell specific Reference Symbol
CSG	Closed Subscriber Group
DL	Downlink
DM	Demodulation
DRB	Data Radio Bearer
E-UTRAN	Evolved UMTS Terrestrial Radio Access Network
eNB/eNodeB	enhanced Node B(base station)
EPC	Evolved Packet Core
EPS	Evolved Packet System
GBR	Guaranteed Bit Rate
GUMMEI	Globally Unique Mobility Management Entity Identifier
HARQ	Hybrid Automatic Repeat reQuest
HeNB	Home eNB
HO	Handover
HOM	Handover Margin
HSPA	High-Speed Packet Access
IE	Information Element
ID	Identity
IP	Internet Protocol
LTE	Long Term Evolution
MAC	Medium Access Control
MBR	Maximum Bit Rate
MME	Mobility Management Entity
MTCP	Multi-path Transmission Control Protocol
NAS	Non-Access Stratum
OAM	Operation and Maintenance
P-GW	PDN Gateway
PBCH	Physical Broadcast CHannel
PCell	Primary Cell
PCFICH	Physical Control Format Indicator CHannel

PCI	Physical Cell Identity
PDCCH	Physical Downlink Control CHannel
PDCP	Packet Data Convergence Protocol
PDN	Packet Data Network
PDSCH	Physical Downlink Shared CHannel
PDU	Packet Data Unit
PHICH	Physical Hybrid ARQ Indicator CHannel
PSS	Primary Synchronization Signal
QCI	QoS Class Identifier
QoS	Quality of Service
RLC	Radio Link Control
RAB	Radio Access Bearer
RAT	Radio Access Technology
RE	Resource Element
RRC	Radio Resource Control
RRH	Remote Radio Head
RRM	Radio Resource Management
RS	Reference Signal
RSCP	Received Signal Code Power
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
S-GW	Serving Gateway
SCell	Secondary Cell
SCTP	Stream Control Transmission Protocol
SDF	Service Data Flow
SDU	Service Data Unit
SRB	Signaling Radio Bearer
SRVCC	Single Radio Voice Call Continuity
SSS	Secondary Synchronization Signal
TCP	Transmission Control Protocol
TTT	Time To Trigger
UE	User Equipment
UL	Uplink
VoIP	Voice over Internet Protocol

10 Summary of Example Embodiments

1. A method, in a source base station, for providing a handover of at least a sub-set of bearers associated with a user equipment, the method comprising:
 - determining **(10)** a need for a handover procedure;
 - selecting **(12)** the sub-set of bearers associated with the user equipment for the handover procedure; and
 - sending **(32)**, to a target base station, a handover request for the sub-set of bearers.
2. The method of example embodiment 1, wherein the selecting **(12)** further comprises analysing **(14)** a mapping, said mapping specifying which, and/or which type of, bearers are to be comprised in the handover procedure.
3. The method of example embodiment 2, wherein the mapping is compiled from at least one predetermined rule.
4. The method of example embodiment 3, wherein the at least one predetermined rule comprises at least one of selecting only non-GBR bearers, only GBR bearers, only GBR bearers with a MBR above or below a certain threshold level, only GBR bearers with GBR above or below a certain threshold level, and/or only bearers that belong to a certain set of QCI's.
 - It should be appreciated that such predetermined rules may also allow for the handover of SRBs.
5. The method of any of example embodiments 1-4, wherein wireless network comprises at least one macro and one pico node or cell in another carrier frequency for high data rate boosting, wherein the selecting **(12)** further comprises selecting **(16)** high data rate bearers for a handover procedure towards the pico node or cell.
 - It should also be appreciated that, according to some of the example embodiments, the wireless network may comprise two macro neighbouring cells or a macro and a neighbouring pico cell of a same frequency and the selecting may further comprise selecting high data rate bearers for a handover procedure towards the neighbouring macro or pico cells.
6. The method of any of example embodiments 1-5, wherein the selecting **(12)** further comprises:
 - configuring **(18)** the user equipment with multiple measurement reporting configurations; and

selecting **(20)** bearers associated with a measurement reporting configuration, of the multiple measurement reporting configurations, that is triggered.

7. The method of any of example embodiments 1-6, wherein the selecting **(12)** further comprises selecting **(22)** bearers which comprise a bearer level above a threshold level.

According to some of the example embodiments, a bearer level may be interpreted as a different triggering threshold level for different bearers, e.g., when it comes to a radio signal level or a buffer level of the bearer.

8. The method of any of example embodiments 1-7, wherein the selecting **(12)** further comprises selecting **(24)** bearers based on a triggering event.

According to some of the example embodiments, triggering events may be defined for selecting bearers for a handover procedure. For example, an A7 event may be defined that this triggered only when the user equipment buffer rises above a specified threshold level for a certain kind of bearers and the radio conditions with the serving cell becomes worse than a specified threshold.

9. The method of any of example embodiments 1-8, wherein the selecting **(12)** further comprises selecting **(26)** bearers based on a load situation at the source base station and/or a target base station.

10. The method of example embodiment 9, further comprising sending and/or receiving **(25)** load status information of the source base station and/or target base station, respectively.

According to some of the example embodiments, the load status exchange may be used to trigger a selective handover procedure.

11. The method of any of example embodiments 1-10, wherein the selecting **(12)** further comprises selecting **(30)** an empty sub-set of bearers.

According to some of the example embodiments, the empty sub-set of bearers may allow for the synchronization of the user equipment to the target base station, thus allowing for the possibility of transmitting future mobility signalling from both the serving and target cell.

According to some of the example embodiments, examining different threshold levels may determine which type of handover procedure to initiate. For example, a first threshold level (low) may invoke an empty handover (e.g., with an empty set of bearers), a second threshold level may invoke a selective handover procedure, and a third threshold level may invoke a full handover procedure. It should be appreciated that the threshold levels may be defined by any means described herein or known in the art.

12. The method of any of example embodiments 1-11, wherein upon completion of the handover procedure, the target base station becomes an anchor node and the source base station becomes a booster node.
13. The method of any of example embodiments 1-12, the target base station is not served to a same soft cell as the source base station.
14. The method of any of example embodiments 1-13, wherein the handover request comprises an information element, said information element comprises a notification that the handover procedure is a selective handover procedure.
15. The method of any of example embodiments 1-14, wherein if the source base station is a booster node, the method further comprising transitioning **(34)** to an anchor node upon detection that the user equipment has lost its previous anchor connection.
16. The method of any of example embodiments 1-15, further comprising maintaining **(36)** a user equipment mobility history, said mobility history comprising a cell identification of a cell the user equipment (or bearer of the user equipment) is located, a cell type, an amount of time the user equipment (or bearer) was located in the cell, an amount of time the user equipment (or bearer) was connected to the cell, etc.

It should be appreciated that the mobility history may be maintained with respect to each bearer of the user equipment. According to some of the example embodiments, the mobility history may further comprise a handover type field providing information on what type of handover procedure was utilized when the user equipment entered the cell. Furthermore, a cell role field may be provided where information on whether the cell was an anchor or booster cell is provided.

According to some of the example embodiments, the mobility history may be a bearer history of each bearer of the user equipment.

17. The method of any of example embodiments 1-16, further comprising receiving **(38)**, from the target base station, a handover request acknowledgement message, said handover request acknowledgement message comprising a listing of all bearers associated with the user equipment and indication for each bearer on whether or not the bearer was admitted at the target.

It should be appreciated that the source base station may keep associations with the non-admitted bearers at the target. According to some of the example embodiments, this may be done in response to a handover which was not successful and therefore a selective handover procedure was implemented.

According to some of the example embodiments, the source base station may save a mapping of bearers which are handed over to the target base station, such that if a request for the same bearers are received by the source, the source base station will know that a user equipment is returning towards the anchor after being selectively handed over for some time. According to some of the example embodiments, the target base station may also keep such a mapping.

18. The method of example embodiment 17, further comprising cancelling **(40)** the handover request based on the listing of bearers or dropping **(42)** the bearers which are indicated as not being admitted to the target.
19. The method of any of example embodiments 1-18, further comprising receiving **(8)**, from the target base station, a handover request acknowledgement message providing a listing of bearers that were not admitted in a full handover procedure.

According to some of the example embodiments, upon receiving notification of the full handover procedure failure, the source base station may thereafter initiate a selective handover as described herein. According to some of the example embodiments, the acknowledgement message may comprise an information element notifying the source base station if the target base station is capable of performing a selective handover.

It should be appreciated that any messages may be sent via the X2 interface. It should also be appreciated that the notification need not be received as a result of a failure. According to some of the example embodiments, a bearer may not have been admitted and the source base station may have decided to switch the handover procedure to a selective handover procedure.

20. The method of any of example embodiments 1-19, wherein the target and source base stations are both booster nodes.

According to some of the example embodiments, booster to booster handover can be performed either directly between the boosters (old booster sending a HANDOVER REQUEST message with an additional indication of the anchor cell to the new booster) or by handing over the bearers from the old booster to the anchor and then to the new booster (where the handover request from the old booster to the anchor includes an additional indication/recommendation of the new booster cell as a final handover target).

21. A source base station, for providing a handover of at least a sub-set of bearers associated with a user equipment, the source base station comprising:
 - processing circuitry **(420A)** configured to determine a need for a handover procedure;
 - the processing circuitry **(420A)** further configured to select the sub-set of bearers associated with the user equipment for the handover procedure; and

radio circuitry **(410A)** configured to send, to a target base station, a handover request for the sub-set of bearers.

22. The source base station of example embodiment 21, wherein the processing circuitry **(420A)** is further configured to analyse a mapping, said mapping specifying which, and/or which type of, bearers are to be comprised in the handover procedure.
23. The source base station of example embodiment 22, wherein the mapping is compiled from at least one predetermined rule.
24. The source base station of example embodiment 23, wherein the at least one predetermined rule comprises at least one of selecting only non-GBR bearers, only GBR bearers, only GBR bearers with a MBR above or below a certain threshold level, only GBR bearers with GBR above or below a certain threshold level, and/or only bearers that belong to a certain set of QCI.

It should be appreciated that such predetermined rules may also allow for the handover of SRBs.

25. The source base station of any of example embodiments 21-24, wherein wireless network comprises at least one macro and one pico node or cell in another carrier frequency for high data rate boosting, wherein the processing circuitry **(420A)** is further configured to select high data rate bearers for a handover procedure towards the pico node or cell.

It should also be appreciated that, according to some of the example embodiments, the wireless network may comprise two macro neighbouring cells or a macro and a neighbouring pico cell of a same frequency and the selecting may further comprise selecting high data rate bearers for a handover procedure towards one of the macro or pico cells.

26. The source base station of any of example embodiments 21-25, wherein the processing circuitry **(420A)** is further configured to configure the user equipment with multiple measurement reporting configurations; and the processing circuitry **(420A)** is also configured to select bearers associated with a measurement reporting configuration, of the multiple measurement reporting configurations, that is triggered.
27. The source base station of any of example embodiments 21-26, wherein the processing circuitry **(420A)** is further configured to select bearers which comprise a bearer level above a threshold level.

According to some of the example embodiments, a bearer level may be interpreted as a different triggering threshold level for different bearers (e.g., when it comes to a radio signal level) or a buffer level of the bearer.

28. The source base station of any of example embodiments 21-27, wherein the processing circuitry **(420A)** is further configured to select bearers based on a triggering event.

According to some of the example embodiments, triggering events may be defined for selecting bearers for a handover procedure. For example, an A7 event may be defined that this triggered only when the user equipment buffer rises above a specified threshold level for a certain kind of bearers and the radio conditions with the serving cell becomes worse than a specified threshold.

29. The source base station of any of example embodiments 21-28, wherein the processing circuitry **(420A)** is further configured to select bearers based on a load situation at the source base station and/or a target base station.

30. The source base station of example embodiment 29, wherein the radio circuitry **(410A)** is further configured to send and/or receive load status information of the source base station and/or target base station, respectively.

According to some of the example embodiments, the load status exchange may be used to trigger a selective handover procedure.

31. The source base station of any of example embodiments 21-30, wherein the processing circuitry **(420A)** is further configured to select an empty sub-set of bearers.

According to some of the example embodiments, the empty sub-set of bearers may allow for the synchronization of the user equipment to the target base station, thus allowing for the possibility of transmitting future mobility signalling from both the serving and target cell.

According to some of the example embodiments, examining different threshold levels may determine which type of handover procedure to initiate. For example, a first threshold level (low) may invoke an empty handover (e.g., with an empty set of bearers), a second threshold level may invoke a selective handover procedure, and a third threshold level may invoke a full handover procedure. It should be appreciated that the threshold levels may be defined by any means described herein or known in the art.

32. The source base station of any of example embodiments 21-31, wherein upon completion of the handover procedure, the target base station becomes an anchor node and the source base station becomes a booster node.

33. The source base station of any of example embodiments 21-32, the target base station is not served to a same soft cell as the source base station.
34. The source base station of any of example embodiments 21-33, wherein the handover request comprises an information element, said information element comprises a notification that the handover procedure is a selective handover procedure.
35. The source base station of any of example embodiments 21-34, wherein if the source base station is a booster node, the processing circuitry **(420A)** is further configured to transition the source base station to an anchor node upon detection that the user equipment has lost its previous anchor connection.
36. The source base station of any of example embodiments 21-35, wherein the processing circuitry **(420A)** is further configured to maintain a user equipment mobility history, said mobility history comprising a cell identification of a cell the user equipment is located, a cell type, an amount of time the user equipment was located in the cell, an amount of time the user equipment was connected to the cell, etc.

It should be appreciated that the mobility history may be maintained with respect to each bearer of the user equipment. According to some of the example embodiments, the mobility history may further comprise a handover type field providing information on what type of handover procedure was utilized when the user equipment entered the cell. Furthermore, a cell role field may be provided where information on whether the cell was an anchor or booster cell is provided.

37. The source base station of any of example embodiments 21-36, wherein the radio circuitry **(410A)** is further configured to receive, from the target base station, a handover request acknowledgement message, said handover request acknowledgement message comprising a listing of all bearers associated with the user equipment and an indication for each bearer on whether or not the bearer was admitted at the target.

It should be appreciated that the source base station may keep associations with the bearers that were not admitted at the target. According to some of the example embodiments, this may be done in response to a handover which was not successful and therefore a selective handover procedure was implemented.

According to some of the example embodiments, the source base station may save a mapping of bearers which are handed over to the target base station, such that if a request for the same bearers are received by the source, the source base station will know that a user equipment

is returning towards the anchor after being selectively handed over for some time. According to some of the example embodiments, the target base station may also keep such a mapping.

38. The source base station of example embodiment 37, wherein the processing circuitry **(420A)** is further configured to cancel the handover request based on the listing of bearers or drop the bearers which are indicated as not being to the target.
39. The source base station of any of example embodiments 21-38, wherein the radio circuitry **(410A)** is further configured to receive, from the target base station, a handover request acknowledgement message providing a listing of bearers that were not admitted in a full handover procedure.

According to some of the example embodiments, upon receiving notification of the full handover procedure failure, the source base station may thereafter initiate a partial or selective handover as described herein. According to some of the example embodiments, the acknowledgement message may comprise an information element notifying the source base station if the target base station is capable of performing a selective handover.

It should be appreciated that any messages may be sent via the X2 interface. It should also be appreciated that the notification need not be received as a result of a failure. According to some of the example embodiments, a bearer may not have been admitted and the source base station may have decided to switch the handover procedure to a selective handover procedure.

40. The source base station of any of example embodiments 21-39, wherein the target and source base stations are both booster nodes.

According to some of the example embodiments, booster to booster handover can be performed either directly between the boosters (old booster sending a HANDOVER REQUEST message with an additional indication of the anchor cell to the new booster) or by handing over the bearers from the old booster to the anchor and then to the new booster (where the handover request from the old booster to the anchor includes an additional indication/recommendation of the new booster cell as a final handover target).

41. A method, in a target base station, for providing a handover of at least a sub-set of bearers associated with a user equipment, the method comprising:
- receiving **(50)**, from a source base station, a handover request for the sub-set of bearers associated with the user equipment;
 - analysing **(52)** a suitability of possibility of admitting the sub-set of bearers comprised in the handover request; and

sending **(64)**, to the source base station, a handover request acknowledgement comprising a result of the analysing.

It should be appreciated that according to some of the example embodiments, the target base station may receive multiple handover requests for a same user equipment from a same source base station. In such an instance, the target base station will not treat the multiple requests as an error but rather as a request to selectively hand even more bearers of the user equipment.

According to some of the example embodiments, any subsequent handover requests may be marked as selective handover requests. In such instances, the target base station may not try to set up SRBs when the user equipment connects to it later on.

42. The method of example embodiment 41, wherein the sub-set of bearers is an empty sub-set of bearers.

According to some of the example embodiments, the empty sub-set of bearers may allow for the synchronization of the user equipment to the target base station, thus allowing for the possibility of transmitting future mobility signalling from both the serving and target cell.

According to some of the example embodiments, examining different threshold levels may determine which type of handover procedure to initiate. For example, a first threshold level (low) may invoke an empty handover (e.g., with an empty set of bearers), a second threshold level may invoke a selective handover procedure, and a third threshold level may invoke a full handover procedure. It should be appreciated that the threshold levels may be defined by any means described herein or known in the art.

43. The method of any of example embodiments 41-42, wherein upon completion of the handover procedure, the target base station becomes an anchor node and the source base station becomes a booster node.
44. The method of any of example embodiments 41-43, the target base station is not served to a same soft cell as the source base station.
45. The method of any of example embodiments 41-44, wherein the handover request comprises an information element, said information element comprises a notification that the handover procedure is a selective handover procedure.
46. The method of any of example embodiments 41-45, wherein if the target base station is a booster node, the method further comprising transitioning **(66)** to an anchor node upon detection that the user equipment has lost its previous anchor connection.

47. The method of any of example embodiments 41-46, further comprising maintaining **(68)** a user equipment mobility history, said mobility history comprising a cell identification of a cell the user equipment (or bearer) is located, a cell type, an amount of time the user equipment (or bearer) was located in the cell, an amount of time the user equipment (or bearer) was connected to the cell, etc.

It should be appreciated that the mobility history may be maintained with respect to each bearer of the user equipment. According to some of the example embodiments, the mobility history may further comprise a handover type field providing information on what type of handover procedure was utilized when the user equipment entered the cell. Furthermore, a cell role field may be provided where information on whether the cell was an anchor or booster cell is provided. It should further be appreciated that the user equipment mobility history may be transferred from the source base station to the target base station during the handover procedure. According to some of the example embodiments, the target base station may keep such a history to adopting policies depending on the mobility.

48. The method of any of example embodiments 41-47, wherein the handover request acknowledgement message comprising a listing of all bearers associated with the user equipment and an indication for each bearer on whether or not the bearer was admitted at the target.

It should be appreciated that the source base station may keep associations with the bearers that were not admitted at the target.

49. The method of any of example embodiments 41-48, further comprising sending **(48)**, to the source base station, a handover request acknowledgement message providing a listing of bearers that were not admitted in a full handover procedure or a handover failure message if none of the bearers could be admitted.

According to some of the example embodiments, the acknowledgement or failure message may comprise an information element notifying the source base station if the target base station is capable of performing a selective handover.

50. The method of any of example embodiments 41-49, wherein the target and source base stations are both booster nodes.

According to some of the example embodiments, booster to booster handover can be performed either directly between the boosters (old booster sending a HANDOVER REQUEST message with an additional indication of the anchor cell to the new booster) or by handing over the bearers from the old booster to the anchor and then to the new booster (where the handover

request from the old booster to the anchor includes an additional indication/recommendation of the new booster cell as a final handover target).

51. The method of any of example embodiments 41-50, further comprising sending **(70)**, to a MME, a path switch request, said path switch request comprising an identification of the sub-set of bearers.
52. The method of any of example embodiments 41-51, wherein the handover request acknowledgement message is an X2 message.
53. A target base station, for providing a handover of at least a sub-set of bearers associated with a user equipment, the target base station comprising:
 - radio circuitry **(410B)** configured to receive, from a source base station, a handover request for the sub-set of bearers associated with the user equipment;
 - processing circuitry **(420B)** configured to analyse a possibility of admitting the sub-set of bearers comprised in the handover request; and
 - the radio circuitry **(410B)** further configured to send, to the source base station, a handover request acknowledgement comprising a result of the analysing.

It should be appreciated that according to some of the example embodiments, the target base station may receive multiple handover requests for a same user equipment from a same source base station. In such an instance, the target base station will not treat the multiple requests as an error but rather as a request to selectively hand over more bearers of the user equipment.

According to some of the example embodiments, any subsequent handover requests may be marked as selective handover requests. In such instances, the target base station may not try to set up SRBs when the user equipment connects to it later on.
54. The target base station of example embodiment 53, wherein the sub-set of bearers is an empty sub-set of bearers.

According to some of the example embodiments, the empty sub-set of bearers may allow for the synchronization of the user equipment to the target base station, thus allowing for the possibility of transmitting future mobility signalling from both the serving and target cell.

According to some of the example embodiments, examining different threshold levels may determine which type of handover procedure to initiate. For example, a first threshold level (low) may invoke an empty handover (e.g., with an empty set of bearers), a second threshold level may invoke a selective handover procedure, and a third threshold level may invoke a full handover

procedure. It should be appreciated that the threshold levels may be defined by any means described herein or known in the art.

55. The target base station of any of example embodiments 53-54, wherein upon completion of the handover procedure, the target base station becomes an anchor node and the source base station becomes a booster node.
56. The target base station of any of example embodiments 53-55, the target base station is not served to a same soft cell as the source base station.
57. The target base station of any of example embodiments 53-56, wherein the handover request comprises an information element, said information element comprises a notification that the handover procedure is a selective handover procedure.
58. The target base station of any of example embodiments 53-57, wherein if the target base station is a booster node, the processing circuitry **(420B)** is further configured to transition to an anchor node upon detection that the user equipment has lost its previous anchor connection.
59. The target base station of any of example embodiments 53-58, wherein the processing circuitry **(420B)** is further configured to maintain a user equipment mobility history, said mobility history comprising a cell identification of a cell the user equipment (or bearer) is located, a cell type, an amount of time the user equipment (or bearer) was located in the cell, an amount of time the user equipment (or bearer) was connected to the cell, etc.

It should be appreciated that the mobility history may be maintained with respect to each bearer of the user equipment. According to some of the example embodiments, the mobility history may further comprise a handover type field providing information on what type of handover procedure was utilized when the user equipment entered the cell. Furthermore, a cell role field may be provided where information on whether the cell was an anchor or booster cell is provided. It should further be appreciated that the user equipment mobility history may be transferred from the source base station to the target base station during the handover procedure. According to some of the example embodiments, the target base station may keep such a history to adopting policies depending on the mobility.

60. The target base station of any of example embodiments 53-59, wherein the handover request acknowledgement message comprising a listing of all bearers associated with the user equipment and an indication for each bearer on whether or not the bearer was admitted at the target.

It should be appreciated that the source base station may keep associations with the bearers that were non-admitted at the target.

61. The target base station of any of example embodiments 53-60, wherein the radio circuitry **(410B)** is further configured to send, to the source base station, a handover request acknowledgement message providing a listing of bearers that were not admitted in a full handover procedure or a handover failure message if non of the bearers could be admitted.

According to some of the example embodiments, the acknowledgement or failure message may comprise an information element notifying the source base station if the target base station is capable of performing a selective handover.

62. The target base station of any of example embodiments 53-61, wherein the target and source base stations are both booster nodes.

According to some of the example embodiments, booster to booster handover can be performed either directly between the boosters (old booster sending a HANDOVER REQUEST message with an additional indication of the anchor cell to the new booster) or by handing over the bearers from the old booster to the anchor and then to the new booster (where the handover request from the old booster to the anchor includes an additional indication/recommendation of the new booster cell as a final handover target).

63. The target base station of any of example embodiments 53-62, wherein the radio circuitry **(410B)** is further configured to send, to a MME, a path switch request, said path switch request comprising an identification of the sub-set of bearers.

64. The target base station of any of example embodiments 53-63, wherein the handover request acknowledgement message is an X2 message.

SELECTIVE HANDOVER: ENABLING UES TO BE SERVED BY MULTIPLE CELLS

1 Technical area/Keywords

Heterogeneous networks, Het Net, Pico, Soft cell, Handover, Handoff, LTE, Rel 12

2 Overview

With the proliferation of user friendly smart phones and tablets, the usage of high data rate services such as video streaming over the mobile network is becoming commonplace, greatly increasing the amount of traffic in mobile networks. Thus, there is a great urgency in the mobile network community to ensure that the capacity of mobile networks keeps up increasing with this ever-increasing user demand. The latest systems such as Long Term Evolution (LTE), especially when coupled with interference mitigation techniques, have spectral efficiencies very close to the theoretical Shannon limit. The continuous upgrading of current networks to support the latest technologies and densifying the number of base stations per unit area are two of the most widely used approaches to meet the increasing traffic demands.

Yet another approach that is gaining high attention is to use Heterogeneous Networks where the traditional pre-planned macro base stations (known as the *macro layer*) are complemented with several low-powered base stations that may be deployed in a relatively unplanned manner. The 3rd Generation Partnership Project (3GPP) has incorporated the concept of Heterogeneous Networks as one of the core items of study in the latest enhancements of LTE, such as LTE release 11. and several low-powered base stations for realizing heterogeneous networks such as *pico* base stations, *femto* base stations (also known as home base stations or HeNBs), relays, and RRHs (remote radio heads) have been defined.

The initial discussion for LTE release 12 has already started and one of the proposed items for study is the possibility of serving a User Equipment (UE) from more than one eNB simultaneously. The current legacy handover mechanisms of LTE have to be updated in order to support this.

3 Description

3.1 Technical Background / Existing Technology

3.1.1 Overall E-UTRAN architecture

The Evolved UMTS Terrestrial Radio Access Network (E-UTRAN) consists of base stations called enhanced NodeBs (eNBs or eNodeBs), providing the E-UTRA user plane and control plane protocol terminations towards the UE. The eNBs are interconnected with each other by means of the X2 interface. The eNBs are also connected by means of the S1 interface to the EPC (Evolved Packet Core), more specifically to the MME (Mobility Management Entity) by means of the S1-MME interface and to the Serving Gateway (S-GW) by means of the S1-U interface. The S1 interface supports many-to-many relation between MMEs / S-GWs and eNBs. The E-UTRAN architecture is illustrated in Figure 1 below.

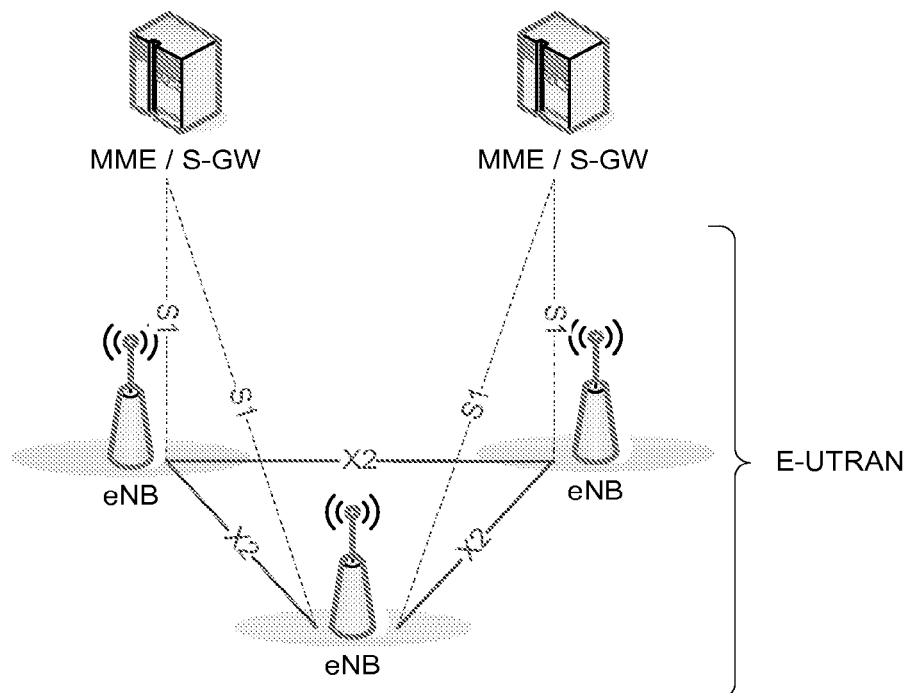


Figure 1: Overall E-UTRAN Architecture

The eNB hosts functionalities such as Radio Resource Management (RRM), radio bearer control, admission control, header compression of user plane data towards serving gateway, routing of user plane data towards the serving gateway. The MME is the control node that processes the signaling between the UE and the CN. The main functions of the MME are related to connection management and bearer management, which are handled via Non Access Stratum (NAS) protocols. The S-GW is the anchor point for UE mobility, and also comprises other functionalities such as temporary DL data buffering while the UE is being paged, packet routing and forwarding the right eNB, gathering of information for charging and lawful interception. The PDN Gateway (P-GW) is the node responsible for UE IP address allocation, as well as Quality of Service (QoS) enforcement (this is explained further in later sections). Figure 2 gives a summary of the functionalities of the different nodes, and the reader is referred to 3GPP TS 36.300 and the references therein for the details of the functionalities of the different nodes. In Figure 2, the yellow boxes depict the logical nodes, white boxes depict the functional entities of the control plane and blue boxes depict the radio protocol layers.

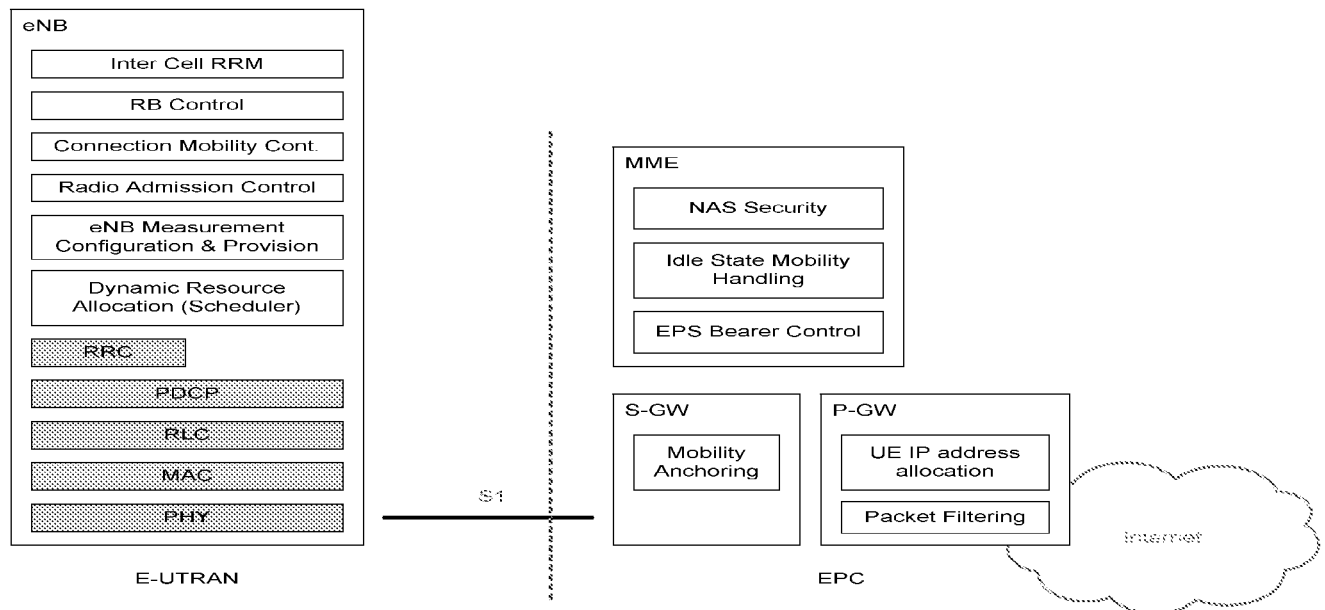


Figure 2: Functional Split between E-UTRAN and EPC

3.1.2 Radio Protocol architecture

The radio protocol architecture of E-UTRAN is divided into the user plane and the control plane.

3.1.2.1 User plane

Figure 3 shows the protocol stack for the user-plane. The user plane protocol stack is comprised of the Packet Data Convergence Protocol (PDCP), Radio Link Control (RLC), and Medium Access Control (MAC), which are terminated at the eNB. The PDCP manages IP packets in the user plane and it performs functionalities such as header compression, security, and re-ordering and retransmission during handover. The RLC layer is mainly responsible for segmentation (and corresponding assembly) of PDCP packets, in order that they fit the size that is actually to be transmitted over the air interface. RLC can operate either in unacknowledged mode or acknowledged mode, where the latter supports retransmissions. The MAC layer performs multiplexing of data from different radio bearers, and it is the one that informs the RLC about the size of the packets to provide, which is decided based on the required QoS of each radio bearer and the current capacity available to the UE.

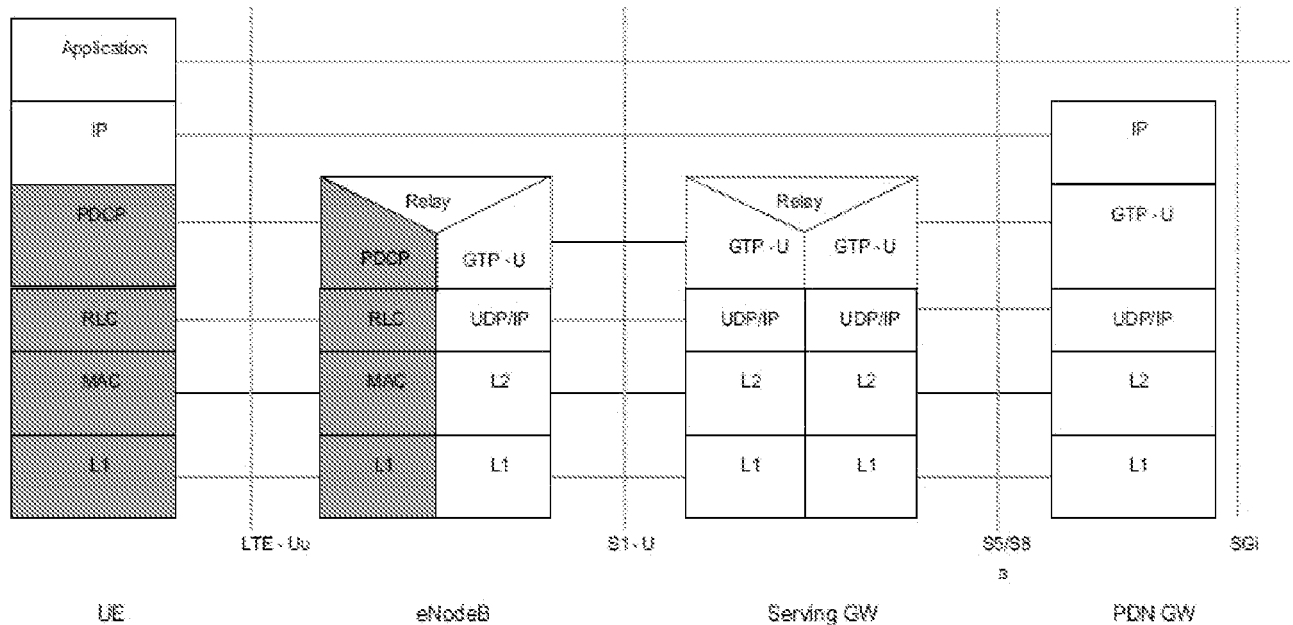


Figure 3: User plane protocol stack

3.1.2.2 Control plane

Figure 4 shows the control plane protocol stack. The layers below the Radio Resource Control (RRC) layer perform the same functionality as in the user plane except that there is no header compression in the control plane. The main functions of the RRC are the broadcasting of system information, RRC connection control (establishment, modification, and release of RRC connection, establishment of signalling radio bearers (SRB) and data radio bearers (DRBs), handover, configuration of lower protocol layers, radio link failure recovery, etc...), and measurement configuration and reporting. The details of the RRC protocol functionalities and procedures can be found in 3GPP TS 36.331.

A UE is uniquely identified over the S1 interface within an eNB with the eNB UE S1AP ID. When an MME receives an eNB UE S1AP ID it stores it for the duration of the UE-associated logical S1-connection for this UE. Once known to an MME this IE is comprised in all UE associated S1-AP signalling. The eNB UE S1AP ID is unique within the eNB, and UEs are assigned new S1AP ID after a handover by the target eNB.

From the MME side, a UE is uniquely identified using the MME UE S1AP ID. When an eNB receives MME UE S1AP ID it stores it for the duration of the UE-associated logical S1 connection for this UE. Once known to an eNB this IE is comprised in all UE associated S1-AP signalling. The MME UE S1AP ID is unique within the MME, and it is changed if the UE's MME changes (for example, handover between two eNBs connected to different MMEs).

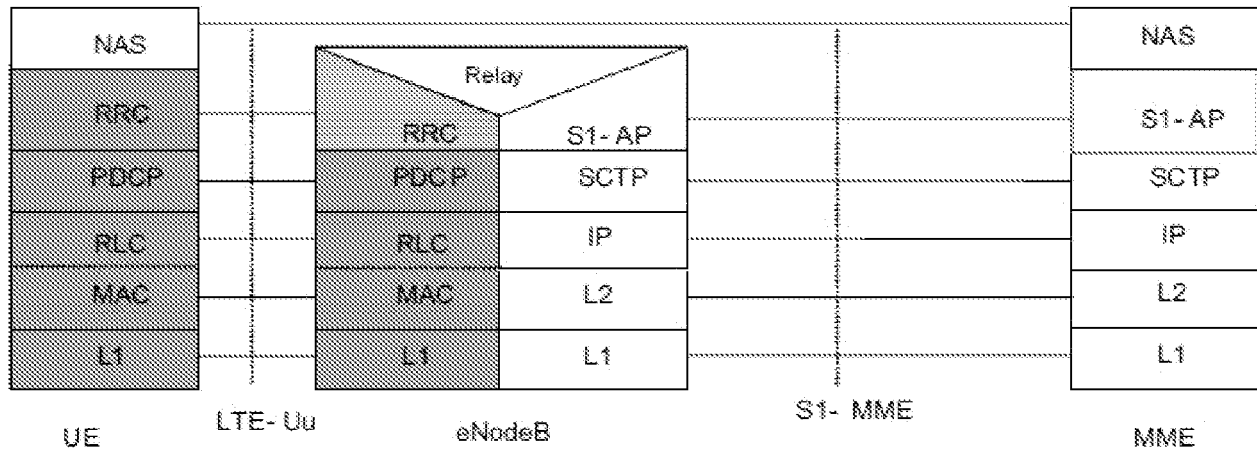


Figure 4: Control plane protocol stack

3.1.2.3 Flow of user plane and control plane data

The flow of user plane and control plane data is illustrated in Figure 5. There is only one MAC entity per UE (unless the UE supports multiple carriers as in the case of carrier aggregation) and under this MAC entity, several Hybrid ARQ (HARQ) processes might be running simultaneously for rapid retransmissions. There is a separate RLC entity for each radio bearer and if the radio bearer is configured to use PDCP, there is also one separate PDCP entity for that bearer. A bearer is configured to use PDCP only if it is dedicated to a UE (i.e. multicast and broadcast data do not utilize PDCP both in the control and user plane and the PDCP is used only for dedicated control message in the control plane and for dedicated UL/DL data in the user plane).

At the transmitting side each layer receives a Service Data Unit (SDU) from a higher layer, and sends a Protocol Data Unit (PDU) to the lower layer. For example, PDCP PDUs are sent towards the RLC, and they are RLC SDUs from RLC point of view, which in turn sends RLC PDUs towards the MAC, which are MAC SDUs from the MAC point of view. At the receiving end, the process is reversed, i.e. each layer passing SDUs to the layer above it, where they are perceived as PDUs.

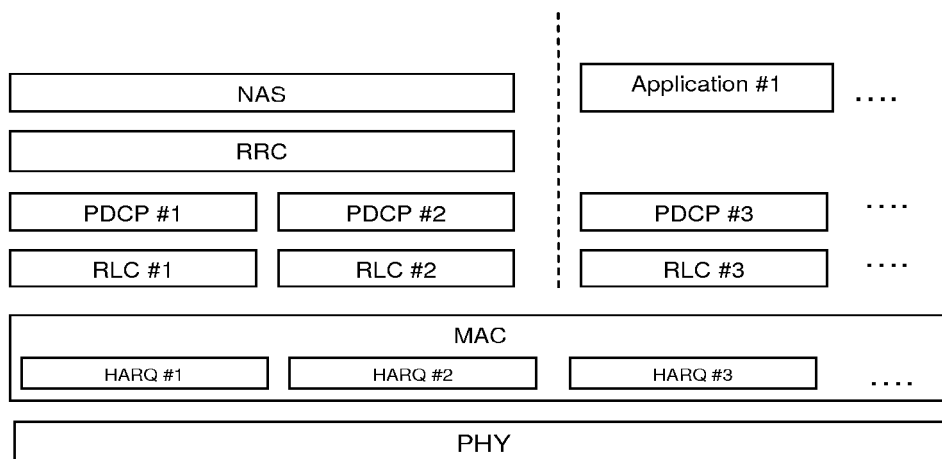


Figure 5: User plane and control plane data flow.

3.1.3 QoS

A UE can have multiple applications running at the same time, each having different QoS requirements (for example, VoIP, browsing, file download ...). In order to support these different requirements, different bearers are set up, each being associated with a QoS. An EPS bearer/E-RAB (Radio Access Bearer) is the level of granularity for bearer level QoS control in the EPC/E-UTRAN. That is, Service Data Flows (SDF) mapped to the same EPS bearer receive the same bearer level packet forwarding treatment (e.g. scheduling policy, queue management policy, rate shaping policy, RLC configuration, etc.) .

One EPS bearer/E-RAB is established when the UE connects to a PDN, and that remains established throughout the lifetime of the PDN connection to provide the UE with always-on IP connectivity to that PDN. That bearer is referred to as the *default* bearer. Any additional EPS bearer/E-RAB that is established to the same PDN is referred to as a *dedicated* bearer. The initial bearer level QoS parameter values of the default bearer are assigned by the network, based on subscription data. The decision to establish or modify a dedicated bearer can only be taken by the EPC, and the bearer level QoS parameter values are always assigned by the EPC.

An EPS bearer/E-RAB is referred to as a GBR bearer if dedicated network resources related to a Guaranteed Bit Rate (GBR) value that is associated with the EPS bearer/E-RAB are permanently allocated (e.g. by an admission control function in the eNB) at bearer establishment/modification. Otherwise, an EPS bearer/E-RAB is referred to as a Non-GBR bearer. A dedicated bearer can either be a GBR or a Non-GBR bearer while a default bearer shall be a Non-GBR bearer.

The EPS bearer service architecture is shown in Figure 6. The packets of an EPS bearer are transported over a radio bearer between the UE and eNB. An S1 bearer transports the packets of an EPS bearer between the eNB and S-GW. An E-RAB is actually a concatenation of these two bearers (i.e. radio bearer and S1 bearer), and the two bearers are mapped on a one to one fashion. An S5/S8 bearer transports the packets of the EPS bearer between the S-GW and P-GW, and completes the EPS bearer. Here also there is a one to one mapping between the E-RAB and S5/S8 bearer.

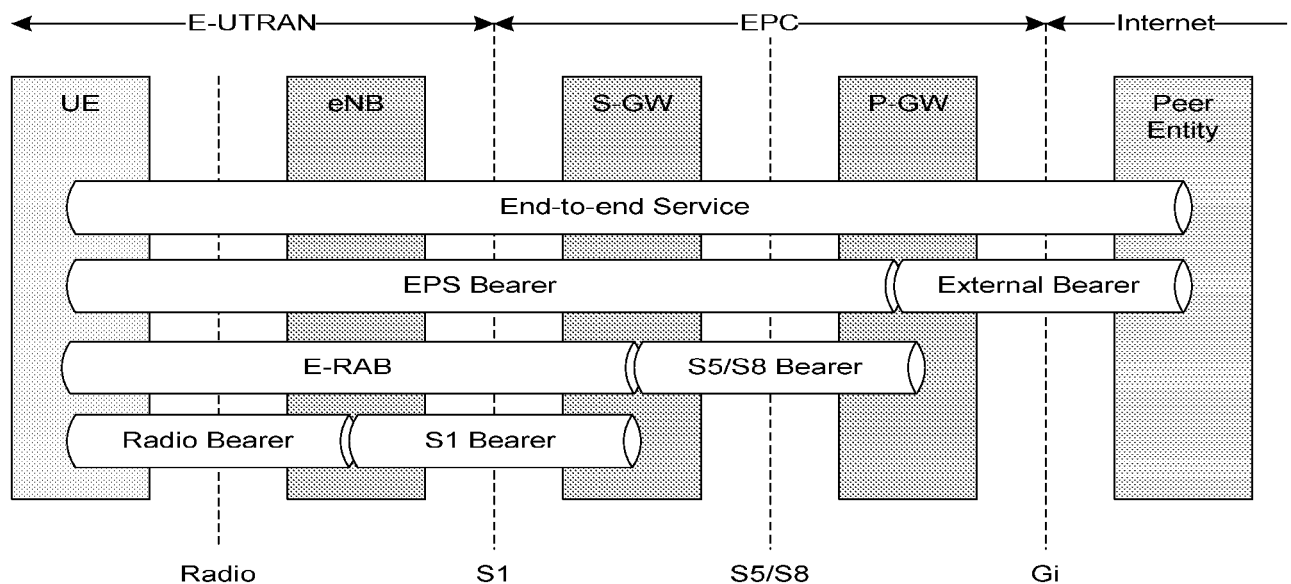


Figure 6: EPS Bearer Service Architecture

The bearer level (i.e. per bearer or per bearer aggregate) QoS parameters are QCI, ARP, GBR, and AMBR. Each EPS bearer/E-RAB (GBR and Non-GBR) is associated with the following bearer level QoS parameters:

- **QoS Class Identifier (QCI):** scalar that is used as a reference to access node-specific parameters that control bearer level packet forwarding treatment (e.g. scheduling weights, admission thresholds, queue management thresholds, link layer protocol configuration, etc.), and that have been pre-configured by the operator owning the eNodeB. Nine QCI values are standardized the detailed requirements of these classes can be found in 3GPP TS 23.203.
- **Allocation and Retention Priority (ARP):** the primary purpose of ARP is to decide whether a bearer establishment / modification request can be accepted or needs to be rejected in case of resource limitations. In addition, the ARP can be used by the eNodeB to decide which bearer(s) to drop during exceptional resource limitations (e.g. at handover).

Each GBR bearer is additionally associated with the following bearer level QoS parameters:

- **Guaranteed Bit Rate (GBR):** the bit rate that can be expected to be provided by a GBR bearer
- **Maximum Bit Rate (MBR):** the maximum bit rate that can be expected to be provided by a GBR bearer. MBR can be greater or equal to the GBR.

Each APN access, by a UE, is associated with a per-APN Aggregate Maximum Bit Rate (APN-AMBR). The APN-AMBR sets the limit on the aggregate bit rate that can be expected to be provided across all Non-GBR bearers and across all PDN connections of the same APN.

Each UE in state EMM-REGISTERED is associated with the bearer aggregate level QoS parameter known as per UE Aggregate Maximum Bit Rate (UE-AMBR). The UE-AMBR

limits the aggregate bit rate that can be expected to be provided across all Non-GBR bearers of a UE.

3.1.4 Heterogeneous Networks and Soft/Shared Cells

The use of a so called *heterogeneous deployment* or *heterogeneous network*, as illustrated in Figure 7, consisting of network transmission nodes with different transmit power operating and with overlapping coverage areas, is considered to be an interesting future deployment strategy for cellular networks. In such a deployment, the low-power nodes (“pico nodes”) are typically assumed to offer high data rates (Mbit/s), as well as provide high capacity (users/m² or Mbit/s/m²), in the local areas where this is needed/desired, while the high-power nodes (“macro nodes”) are assumed to provide full-area coverage. In practice, the macro nodes may correspond to currently deployed macro cells while the pico nodes are later deployed nodes, extending the capacity and/or achievable data rates within the macro-cell coverage area where needed.

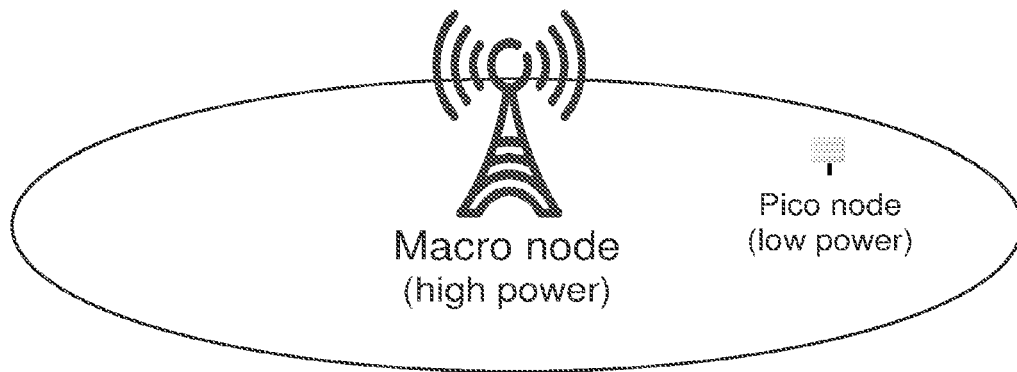


Figure 7: Heterogeneous deployment with a higher-power macro node and a lower-power pico node. In a typical case, there may be multiple pico nodes within the coverage area of a macro node.

A pico node of a heterogeneous deployment may correspond to a cell of its own (a “pico cell”), see Figure 8. This means that, in addition to downlink and uplink data transmission/reception, the pico node also transmits the full set of common signals/channels associated with a cell. In the LTE context this comprises:

- The *Primary and Secondary Synchronization Signals* (PSS and SSS) corresponding to the *Physical Cell Identity* of the pico cell.
- The *Cell-specific reference signals* (CRS), also corresponding to the Physical Cell Identity of the cell. The CRS can e.g. be used for downlink channel estimation to enable coherent demodulation of downlink transmissions.
- The *Broadcast channel* (BCH), with corresponding pico-cell system information¹

As the pico node transmits the common signals/channels, the corresponding pico cell can be detected and selected (connected to) by a terminal (UE, user equipment).

¹ Additional system information is transmitted on the PDSCH physical channel

If the pico node corresponds to a cell of its own, also so-called *L1/L2 control signaling* on the PDCCH (as well as PCFICH and PHICH) are transmitted from the pico node to connected terminals, in addition to downlink data transmission on the PDSCH. The L1/L2 control signaling e.g. provides downlink and uplink scheduling information and Hybrid-ARQ-related information to terminals within the cell. This is shown in Figure 8.

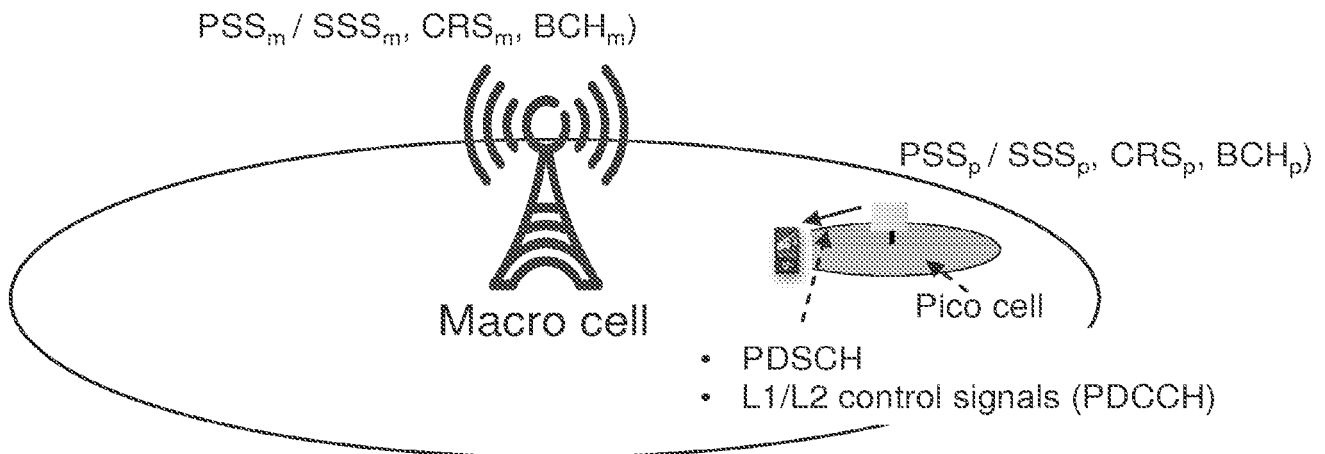


Figure 8: Heterogeneous deployment where the pico node corresponds to a cell of its own (a "pico cell"). The indices "p" and "m" indicate common signals/channels for the pico and macro cell respectively.

Alternatively, a pico node within a heterogeneous deployment may not correspond to a cell of its own but may just provide a data-rate and capacity "extension" of the overlaid macro cell, see e.g. P32215. This is sometimes known as "shared cell" or "soft cell". In this case at least the CRS, PBCH, PSS and SSS are transmitted from the macro node. The PDSCH can be transmitted from the pico node. To allow for demodulation and detection of the PDSCH, despite the fact that no CRS is transmitted from the pico node, DM-RS should be transmitted from the pico node together with the PDSCH. The UE-specific reference signals can then be used by the terminal for PDSCH demodulation/detection. This is shown in Figure 9.

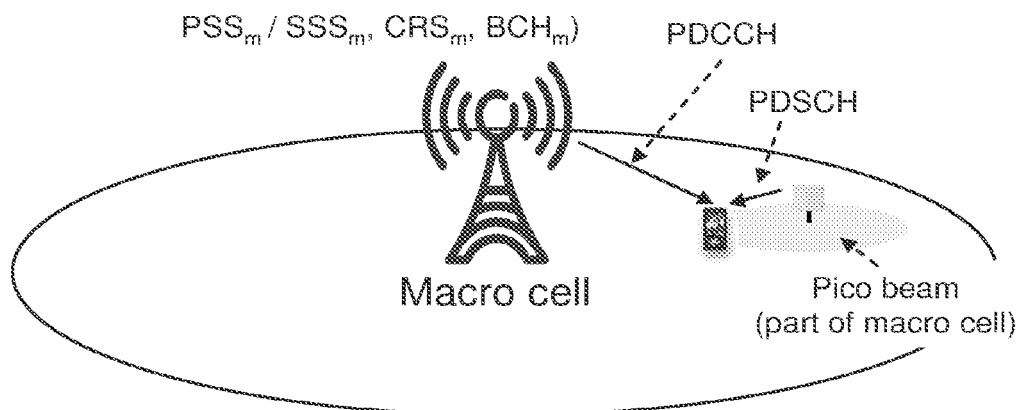


Figure 9: Heterogeneous deployment where the pico node does not correspond to a cell of its own

Transmitting data from a pico node not transmitting CRS as described above requires DM-RS support in the terminal (“non-legacy terminal”). In LTE, DM-RS-based PDSCH reception is supported in Rel-10 and for FDD while for the L1/L2 control signalling, DM-RS-based reception is planned for Rel-11. For terminals not supporting DM-RS-based reception (“legacy terminals”) one possibility in a shared cell setting is to exploit SFN²-type of transmission. In essence *identical* copies of the signals and channels necessary for a legacy terminal are transmitted *simultaneously* from the macro and pico nodes. From a terminal perspective this will look as a single transmission. Such an operation, which is illustrated in Figure 10, will only provide an SINR gain, which can be translated into a higher data rate but not a capacity improvement, as transmission resources cannot be reused across sites within the same cell.

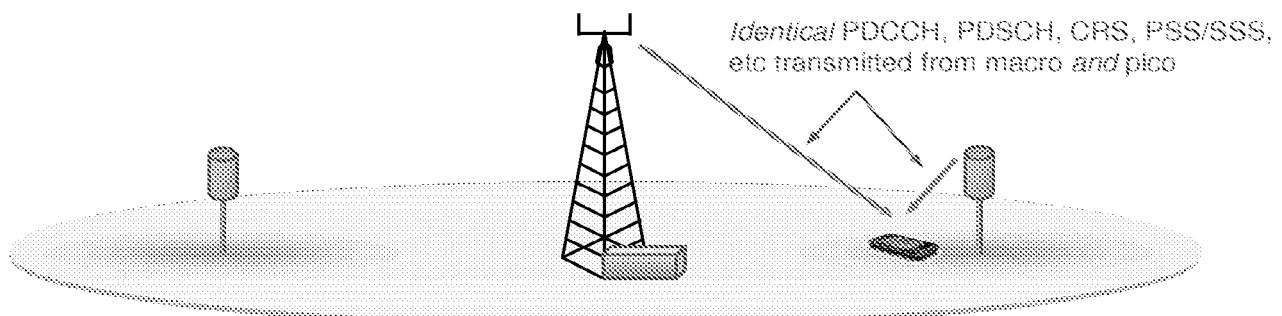


Figure 10: SFN operation with *identical* transmission from macro and pico to a terminal.

If we can assume that the macros are able to provide coverage and the picos are there only for capacity enhancements (i.e. no coverage holes), another alternative architecture is where the UE maintains the macro connectivity all the time (called the “anchor” link), and adds the pico connectivity when it is in the coverage area of the pico (called the “booster” link). When both connections are active, the anchor link can be used either for control signalling while the booster link is used for data. However, it will still be possible to send data also via the anchor link. This is illustrated in Figure 11. Note that in this case, as in the previous cases, the system information is shown to be sent only from the macro, but it is still possible to send it also from the picos.

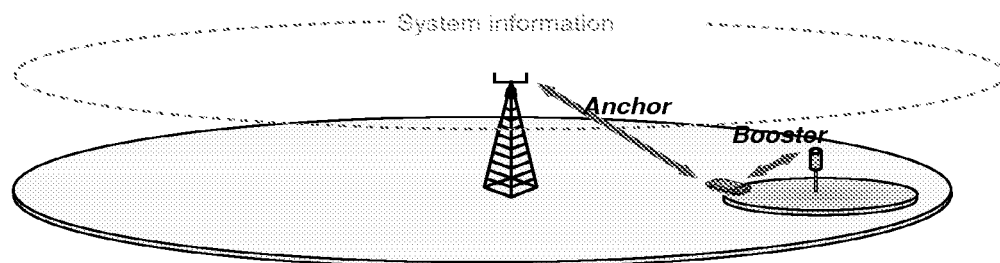


Figure 11: Soft cell operation with the UE having multiple connections with both the anchor and booster.

² Single Frequency Network

3.1.4.1 Protocol architecture for Soft Cells

In order to support multiple connectivity, several architectural options are possible both for the control and user plane. For the user plane, we can have a centralized approach where the PDCP (or even the RLC) is terminated at the anchor only and the booster terminates at the RLC (or even the MAC) level. A decentralized approach will be to have the booster to terminate at the PDCP level. Similar approach can be taken in the control plane (i.e. distributed or centralized PDCP/RLC,) but on top of that we have the additional dimension of centralizing or distributing the RRC. Figure 12 shows example control and user plane architectures, where the user plane is employing distributed PDCP, while the control plane is centralized at the PDCP level at the anchor. Note that in the figure, user plane aggregation (i.e. the possibility to split the packets belonging to one application data flow over the anchor and booster links) can be realized by using a higher layer aggregation protocol like multi-path TCP (MPTCP). According to some of the example embodiments, the control plane is assumed to be like the one shown in the figure.

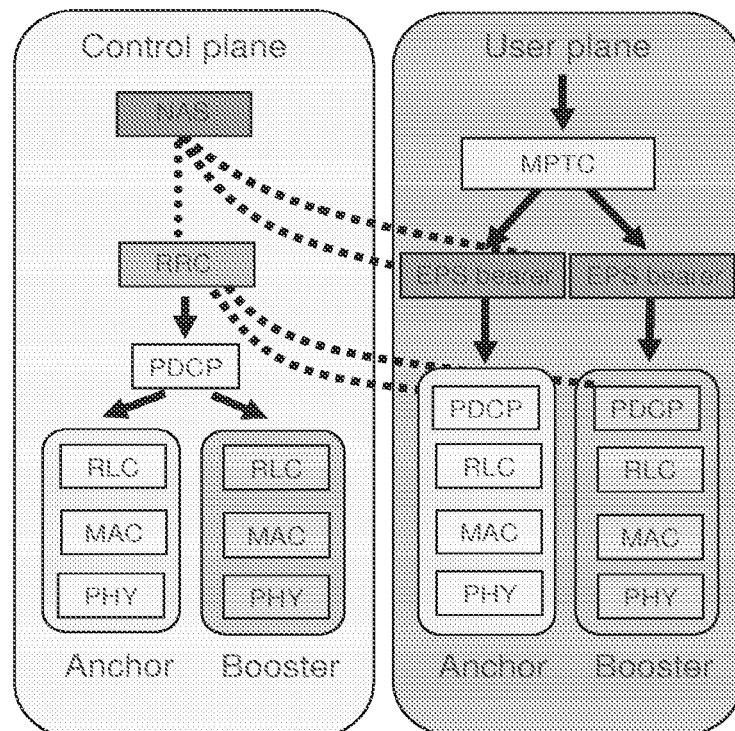


Figure 12: Example protocol architecture for multiple connectivity.

3.1.5 UE measurements

UEs can be configured to report measurements, mainly for the sake of supporting mobility. As specified in 3GPP TS 36.331, the E-UTRAN provides the measurement configuration applicable for a UE in *RRC_CONNECTED* by means of dedicated signalling, i.e. using the *RRCConnectionReconfiguration* message. The following measurement configurations can be signalled to the UE:

1. **Measurement objects:** These define on what the UE should perform the measurements – such as a carrier frequency. The measurement object may also comprise a list of cells to be considered (white-list or black-list) as well as associated parameters, e.g. frequency- or cell-specific offsets.

2. **Reporting configurations:** These consist of the periodic or event-triggered criteria which cause the UE to send a measurement report, as well as the details of what information the UE is expected to report (e.g. the quantities, such as Received Signal Code Power (RSCP) for UMTS or Reference Signal Received Power (RSRP) for LTE, and the number of cells).
3. **Measurement identities:** These identify a measurement and define the applicable measurement object and reporting configuration. Each measurement identity links one measurement object with one reporting configuration. By configuring multiple measurement identities it is possible to link more than one measurement object to the same reporting configuration, as well as to link more than one reporting configuration to the same measurement object. The measurement identity is used as a reference number in the measurement report.
4. **Quantity configurations:** The quantity configuration defines the filtering to be used on each measurement. One quantity configuration is configured per RAT type, and one filter can be configured per measurement quantity.
5. **Measurement gaps:** Measurement gaps define time periods when no uplink or downlink transmissions will be scheduled, so that the UE may perform the measurements (e.g. inter-frequency measurements where the UE has only one Tx/Rx unit and supports only one frequency at a time). The measurement gaps are common for all gap-assisted measurements

The E-UTRAN configures only a single measurement object for a given frequency, but more than one measurement identity may use the same measurement object. The identifiers used for the measurement object and reporting configuration are unique across all measurement types. It is possible to configure the quantity which triggers the report (RSCP or RSRP) for each reporting configuration.

In LTE, examples of measurements metric used are the Reference Signal Received Power (RSRP) and Reference Signal Received Quality (RSRQ). RSRP is a cell specific measure of signal strength and it is mainly used for ranking different cells for handover and cell reselection purposes, and it is calculated as the linear average of the power of the Resource Elements (REs) which carry cell-specific Reference Signals (RSs). The RSRQ, on the other hand, also takes the interference into consideration by taking the total received wideband power into account as well.

One of the measurement configuration parameters that UEs receive from their serving eNBs is the *S-measure*, which tells the UE when to start measuring neighbouring cells. If the measured RSRP of the serving cell falls below the S-measure, indicating the signal of the serving cell is not that strong anymore, the UE starts measuring the signal strength of RSs from the neighbouring cells. The S-measure is an optional parameter and different S-measure values can be specified for initiating intra-frequency, inter-frequency and inter-RAT measurements.

Once the UE is enabled for measuring, it can report any of the following:

- The serving cell
- Listed cells (i.e. cells indicated as part of the measurement object);
- Detected cells on a listed frequency (i.e. cells which are not listed cells but are detected by the UE).

There are several measurement configuration parameters that specify the triggering of measurement reports from the UE. The following event-triggered criteria are specified for intra-RAT measurement reporting in LTE:

- **Event A1:** Primary serving cell (PCell) becomes better than absolute threshold.
- **Event A2:** PCell becomes worse than absolute threshold.
- **Event A3:** Neighbour cell becomes better than an offset relative to the PCell.
- **Event A4:** Neighbour cell becomes better than absolute threshold.
- **Event A5:** PCell becomes worse than one absolute threshold and neighbour cell becomes better than another absolute threshold.
- **Event A6:** Neighbour cell becomes better than an offset relative to a secondary cell (SCell)

For inter-RAT mobility, the following event-triggered reporting criteria are specified:

- **Event B1:** Neighbour cell becomes better than absolute threshold.
- **Event B2:** Serving cell becomes worse than one absolute threshold and neighbour cell becomes better than another absolute threshold.

An example of a measurement report triggering event related to handover is A3, and its usage is illustrated in Figure 13. The triggering conditions for event A3 can be formulated as:

$$N > S + HOM \quad (1)$$

where N and S are the signal strengths of the neighbour and serving cells, respectively, and HOM is the handover margin. HOM is the difference between the radio quality of the serving cell and the radio quality needed before attempting a handover. The radio quality is measured either using RSRP or RSRQ (see 36.133 for further explanation).

The UE triggers the intra-frequency handover procedure by sending event A3 report to the eNB. This event occurs when the UE measures that the target cell is better than the serving cell with a margin “HOM”. The UE is configured over RRC when entering a cell and the HOM is calculated from the following configurable parameters:

$$HOM = Of_s + Ocs + Off - Of_n - Ocn + Hys$$

Where:

Of_s is the frequency specific offset of the serving cell

Ocs is the cell specific offset (CIO) of the serving cell

Off is the a3-Offset

Of_n is the frequency specific offset of the neighbor cell

Ocn is the CIO of the neighbor cell

Hys is the hysteresis

If the condition in (1) is satisfied and it remains valid for a certain duration known as Time To Trigger (TTT), the UE sends a measurement report to the serving eNB (in Figure 3, event A3 is satisfied at point A and measurement report is sent at point B in time). When the serving eNB gets the measurement report, it can initiate a handover towards the neighbour.

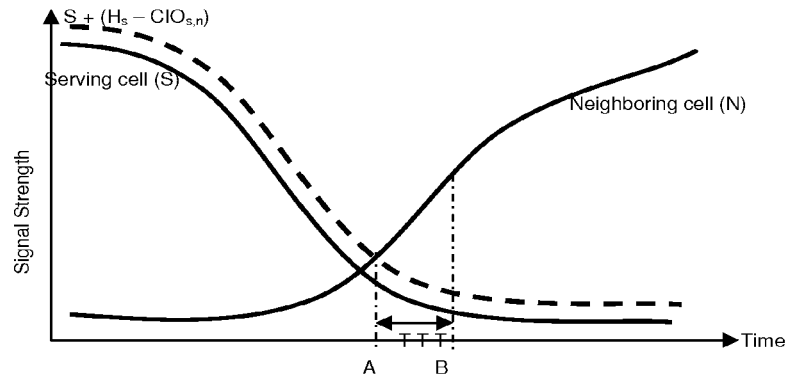


Figure 13: Handover triggering in LTE

In addition to event-triggered reporting, the UE may be configured to perform periodic measurement reporting. In this case, the same parameters may be configured as for event-triggered reporting, except that the UE starts reporting immediately rather than only after the occurrence of an event.

3.1.6 Handover

Handover is one of the important aspects of any mobile communication system, where the system tries to assure service continuity of the User Equipment (UE) by transferring the connection from one cell to another depending on several factors such as signal strength, load conditions, service requirements, etc. The provision of efficient/effective handovers (minimum number of unnecessary handovers, minimum number of handover failures, minimum handover delay, etc.), would affect not only the Quality of Service (QoS) of the end user but also the overall mobile network capacity and performance.

In LTE, UE-assisted, network controlled handover is utilized (3GPP TS 36.300). The handover is based on UE reports, and the UE is moved, if required and possible, to the most appropriate cell that will assure service continuity and quality.

Handover is performed via the X2 connection, whenever available, and if not, using S1 (i.e. involving the Core Network (CN)). The X2 Handover process is shown in Figure 14. The handover procedure can be sub divided into three stages of *preparation (initiation)*, *execution* and *completion*.

The main steps of the handover process are:

1. The source eNB configures the UE measurement procedures. This can be done either when the UE first connects to an eNB (comprised in the HO command as described later) or later one by sending measurement reconfigurations. The measurement configurations are sent to the UE by using the *measConfig* Information Element (IE) that is comprised in the *RRCConnectionReconfiguration* message.
2. The UE is triggered to send a measurement report by the measurement rules set as described in the previous section

3. Based on the received measurement report and other RRM information, the source eNB makes a decision to hand over the UE to the target.
4. The source eNB issues a HANDOVER REQUEST message to the target eNB passing necessary information to prepare the HO at the target side. The source eNB must indicate the cause of the HO in this message, which can be, e.g.,
 - a. Handover Desirable for Radio Reasons,
 - b. Resource Optimization Handover,
 - c. Reduce Load in Serving Cell
5. Admission Control may be performed by the target eNB.
6. The target eNB prepares HO with L1/L2 and sends the HANDOVER REQUEST ACKNOWLEDGE to the source eNB. The HANDOVER REQUEST ACKNOWLEDGE message comprises an Information Element (IE) called "Target eNB to Source eNB Transparent Container". This IE is basically comprises the handover command message (*RRCCConnectionReconfiguration* that comprises the *mobilityControlInfo* IE) that is sent to the UE in the next step. Some of the main elements of the *RRCCConnectionReconfiguration* message are:
 - a. An optional measurement configuration (*measConfig* IE) to be used in the target cell
 - b. Mobility control information (*mobilityControlInfo* IE), which is comprised only during handovers. This IE comprises information the UE needs to execute the handover such as the PCI of the target cell, Cell Radio Network Temporary Identifier (C-RNTI) assigned to the UE in the target cell, timer value for handover expiry, dedicated preamble for Random Access Channel (RACH) in the target cell, carrier frequency/bandwidth to be used in the UL/DL and common radio resource configurations.
 - c. Dedicated radio resource configuration (*radioResourceConfigDedicated* IE), which mainly comprises lists of DRB/SRBs to add or modify (*srb-ToAddModList* and *drb-ToAddModList* IEs, respectively) and if the list of DRBs to release, if any (*drb-ToReleaseList* IE). The lists are populated based on the admission control decision.

Additional information can also be comprised in the *RRCCConnectionReconfiguration* message such as information related to security and carrier aggregation.

NOTE: As soon as the source eNB receives the HANDOVER REQUEST ACKNOWLEDGE, or as soon as the transmission of the handover command is initiated in the downlink, user plane data forwarding may be initiated.
7. The source eNB sends the handover command (i.e. *RRCCConnectionReconfiguration* message comprising the *mobilityControlInfo*) towards the UE on behalf of the target eNB.
8. The source eNB sends the SN (Sequence Number) STATUS TRANSFER message to the target eNB, which comprises the ID of the impacted E-RABs and PDCP SNs for UL and DL data transfer.

9. After receiving the *RRConnectionReconfiguration* message comprising the *mobilityControlInfo*, UE performs synchronisation to target eNB and accesses the target cell via RACH. If the received *RRConnectionReconfiguration* comprised dedicated RACH information, the dedicated preamble comprised in there is used for the RACH access. Otherwise, a contention based approach is taken. Also based on the DRB and SRB information comprised in the *radioResourceConfigDedicated* IE, the UE:
 - a. Resets the MAC
 - b. Re-establishes the PDCP for all the RBs that are established (using the new security keys provided from the target)
 - c. Releases all the DRBs indicated in the *drb-ToReleaseList* (which comprises releasing the associated PDCP, RLC entities and DTCH logical channel)
 - d. Reconfigures all the DRBs indicated in the *drb-ToAddModList* by reconfiguring the associated PDCP, RLC entities and DTCH logical channels using the configuration parameters comprised in the *drb-ToAddModList*
 - e. Reconfigures all the SRBs indicated in the *srb-ToAddModList* by reconfiguring the associated RLC entity and DCCH logical channel used.
10. The target eNB responds with UL allocation and timing advance.
11. When the UE has successfully accessed the target cell, the UE sends the *RRConnectionReconfigurationComplete* message to the target to confirm that the handover succeeded. Optionally, the UE can indicate to the target if it has information regarding earlier Radio Link Failure (RLF) or other logged measurements that could be used for optimization purposes. After the confirmation is received, the target eNB can begin sending data to the UE and the UE can send data to the target based on the scheduling grants it is receiving. However, the data from the CN is still routed to the source eNB.
12. The target eNB sends a PATH SWITCH REQUEST message to MME to inform that the UE has changed cell.
13. The MME sends a MODIFY BEARER REQUEST message to the Serving Gateway.
14. The Serving Gateway switches the downlink data path to the target side. The Serving gateway sends one or more "end marker" packets on the old path to the source eNB and then can release any U-plane/TNL resources towards the source eNB.
15. The Serving Gateway sends a MODIFY BEARER RESPONSE message to MME.
16. The MME confirms the PATH SWITCH REQUEST message with the PATH SWITCH REQUEST ACKNOWLEDGE message.
17. By sending the UE CONTEXT RELEASE message, the target eNB informs success of HO to source eNB and triggers the release of resources by the source eNB.
18. Upon reception of the UE CONTEXT RELEASE message, the source eNB can release radio and C-plane related resources associated to the UE context. Any ongoing data forwarding may continue.

3.2 Overview of the example embodiments

LTE currently supports only one to one connections between UEs and eNBs. As such, when a handover is initiated, the target is asked to admit all the bearers of the UE. If for some reason, such as overload situation, that some of the bearers can't be admitted at the target, the source can either cancel the handover (and possibly try another candidate target) or accept it and handover the UE to the target, which will result in the dropping of the non-admitted bearers. This can have severe consequences on the overall experience of the user.

Current specifications do not allow the setup of bearers in parallel and in multiple eNBs for the same UE, which is needed for enabling multiple connectivity. This would allow an optimal distribution of bearers depending on their QoS and UL/DL requirements.

Some of the example embodiments presented herein address how to enable mobility and bearer management procedures allowing for distribution of UE bearers across multiple eNBs with the possibility to connect a UE to multiple eNBs.

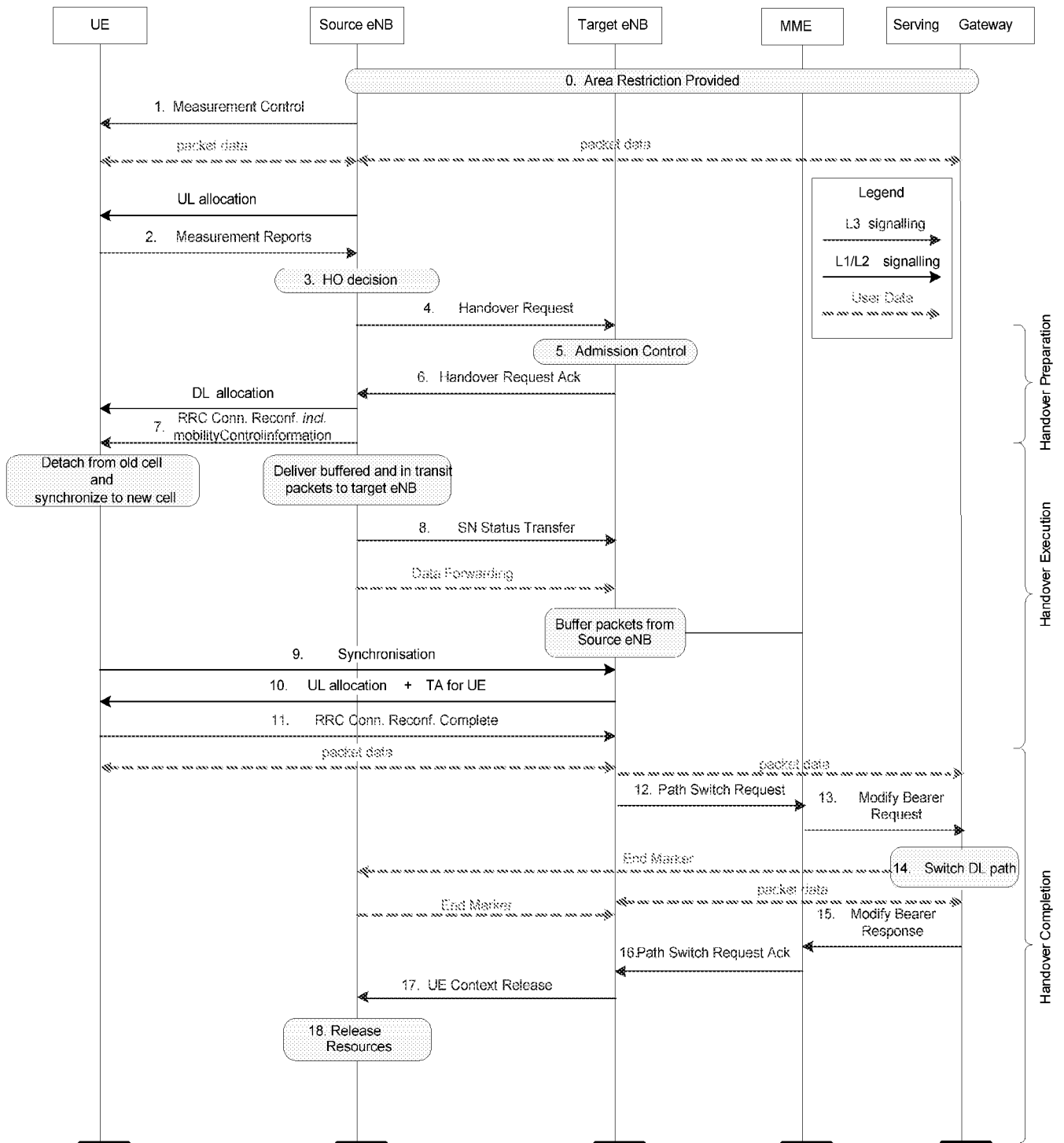


Figure 14: X2 Handover in LTE

4 Brief summary of the example embodiments

According to some of the example embodiments, different mechanisms for enabling multiple connectivity between a UE and multiple cells are proposed. Different selective handover and related bearer management and measurement configuration procedures are described. In a related lvD (P38076), the basic concept of selective handover as well as the required changes in the communication of eNBs involved in the selective handover has been described. According to some of the example embodiments, the main focus is the communication aspects between the eNB (specifically, the anchor) and the UE.

5 Detailed description of the example embodiments

5.1 A non-limiting example implementation

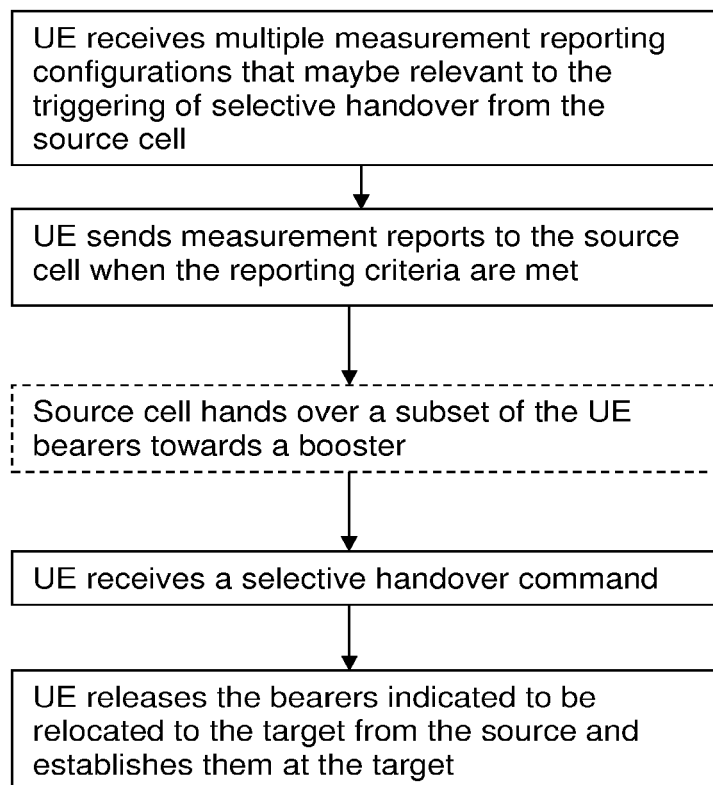


Figure 15: General overview of the example embodiments

A non-limiting example of some of the example embodiments is shown in Figure 15 (where the dotted box showing the procedure that is not the focus of the example embodiments presented herien). The details of some of the example embodiments are given below. For the sake of brevity, the descriptions below treat mostly the case of dual connectivity with two cells, but the ideas are equally applicable for the case where the UE is connected to more than two cells at the same time.

According to some of the example embodiments, a UE is instructed to hand over only a sub set of its bearers towards a target cell while maintaining the other bearers with the original serving cell.

According to some of the example embodiments, a UE is asked to perform an empty handover to a target (i.e. no bearers comprised in the bearers to be handed over list), just to prepare the UE for future selective handovers. For example, when the signal quality of a neighbor cell reaches a certain threshold, the UE is asked to perform this empty handover. After the empty handover, the UE still has all the bearers (both DRBs and SRBs) terminated at the source. However, the UE now has time alignment and synchronization with the target cell.

According to some of the example embodiments, a new UE radio access capability parameter is defined that indicates whether a UE supports multiple connectivity or not. This could be a simple Boolean flag (the presence of which indicating support), or a detailed parameter that comprises information such as the maximum number of support links and any other multiple connectivity related restrictions.

According to some of the example embodiments, a selective handover is indicated to the UE by comprising an empty *srb-ToAddModList* or not comprising it at all (in the *radioResourceConfigDedicated* IE of the *RRCCConnectionReconfiguration* message), which is a clue to the UE that the SRBs still remain with the source and as such it is a selective handover.

According to some of the example embodiments, a new optional IE called “Selective HO” in the *mobilityControlInfo* IE. This IE can take different values depending on the type of selective handover that is being requested. For example, it can have two values, a value of “0” referring to “data radio bearers” (meaning only the data radio bearers listed in the *drb-ToAddModList* are to be handed over) and “1” referring to “signaling radio bearers” (meaning signaling radio bearers indicated in the *srb-ToAddModList* as well as the data radio bearers comprised in the *drb-ToAddModList* are to be handed over). This way of communicating selective handover allows the possibility to switch the anchor node from the source to the target.

According to some of the example embodiments, a selective handover is indicated to the UE by not comprising the *radioResourceConfigDedicated* IE in the *RRCCConnectionReconfiguration* message. This is a special kind of selective handover, which we refer to as “empty handover”, which can be used to set up a communication link with the target without actually handing over any DRBs or SRBs.

According to some of the example embodiments, the indication that the handover is selective is added to the handover command message that is sent to the UE by the target. The target, upon receiving a selective handover request from the source, will use one of the methods described above to construct the *RRCCConnectionReconfiguration* message that is sent towards the source via the *Target eNB to Source eNB Transparent Container* IE of the handover request acknowledgment which is then forwarded to the UE as the handover command from the source.

According to some of the example embodiments, the indication that the handover is selective is added to the handover command message that is sent to the UE by the source. The target will send a legacy *RRCCConnectionReconfiguration* message that is sent towards the source via the *Target eNB to Source eNB* IE of the handover request acknowledgment. When the source receives this as a response to a selective handover it has sent out, it will modify the *RRCCConnectionReconfiguration* message using one of the methods described above, and forwards this to the UE as the handover command.

According to some of the example embodiments, when the UE receives an *RRCCConnectionReconfiguration* message indicating a selective handover, it will perform the following main actions:

- a. Start synchronizing to the downlink of the target cell.
- b. Add the indicated C-RNTI to the list of C-RNTIs being used and associate it with the target cell (e.g. using the target cell's PCI)
- c. Initializes a new protocol stack that corresponds with the target cell and configures the MAC and PHY layers by applying default configurations as well as on the configurations indicated in the *radioResourceConfigCommon* and other relevant IEs of the *mobilityControlInfo*.
- d. Release all the DRBs comprised in the *drb-ToReleaseList* (which comprises releasing the associated PDCP, RLC entities and DTCH logical channel)
- e. Establish the PDCP, RLC and DTCH for all the DRBs in the *drb-ToAddModList* in the newly configured protocol stack that is associated with the target cell, using the protocol configurations comprised in the list and for the PDCP, additionally utilizing the new security configurations.
- f. Transfer any outstanding PDCP SDUs (i.e. those that are in the retransmission buffer of the anchor) of all the DRBs in the *drb-ToAddModList* to which lossless handover is applicable to the corresponding new PDCP entities that are setup in the previous step.
- g. Release all the DRBs comprised in the *drb-ToAddModList* (which comprises releasing the associated PDCP, RLC entities and DTCH logical channel) from the source protocol stack
- h. If the *srb-ToAddModList* is comprised and not empty, which indicates the switching of the anchor, then setup the SRBs in the new protocol stack by applying the default SRB configurations as well as establishing the PDPC (if needed, and if so applying the new security settings), RLC and DCCH based on the configurations comprised in the in the *srb-ToAddModList*) and release the SRBs from the protocol stack associated with the source.

According to some of the example embodiments, if the selective handover is of the type for adding a booster (i.e. only DRBs handed over to the target), the target replies to the random access synchronization request of the UE by comprising a random access response that comprises a timing advance command, but no uplink grant.

According to some of the example embodiments, if the selective handover is of the type for adding a booster (i.e. only DRBs handed over to the target), the UE, upon the completion of the handover procedure (i.e. synchronization with the target, reception of Timing advance from the target and configuring the protocol stack corresponding with the target), sends out an *RRCCConnectionReconfigurationComplete* message towards the anchor.

According to some of the example embodiments, if the selective handover is of the type for adding a booster (i.e. only DRBs handed over to the target) and the UE does not have enough resources to transmit the *RRCCConnectionReconfigurationComplete* message towards the anchor, it can request for an UL grant using a scheduling request.

According to some of the example embodiments, if the selective handover is of the type for switching the anchor (i.e. SRBs handed over to the target), the target replies to the random access synchronization request of the UE by comprising a random access response that comprises a timing advance command and also an uplink grant.

According to some of the example embodiments, if the selective handover is of the type for switching the anchor (i.e. SRBs handed over to the target), the UE, upon the completion of the handover procedure (i.e. synchronization with the target, reception of Timing advance and UL grant from the target and configuring the protocol stack corresponding with the target), sends out an *RRCConnectionReconfigurationComplete* message towards the new anchor.

According to some of the example embodiments, a UE is configured by the anchor with multiple measurement reporting configurations, and sends these reports independently of each other when their measurement triggering criteria are fulfilled. As a simple example, the anchor can configure two measurement configurations based on the A3 Event, and set different threshold values for each. Note that this is just an example, and other events can be used to select different bearers.

According to some of the example embodiments, a UE is configured with new triggering events which are defined specifically for selective handover. For example, an A7 event may be defined in the *reportConfigEUTRA* IE of the measurement reporting configuration, which is triggered only when the UE buffer rises above a specified threshold level for certain kind of bearers and the radio conditions with the serving cell becomes worse than a specified threshold.

According to some of the example embodiments, the UE is configured with multiple sets of measurements, some applicable to all cells, some applicable only to cells that support selective handovers, and some applicable only to cells that support full handovers only. This can be achieved in several ways, for example:

- The anchor explicitly comprises all the neighboring cells of a certain type in the corresponding measurements configurations.
- The anchor indicates, for example via a new IE in the measurement configuration called “Cell HO capability”, to which type of cells the measurement configuration applies. This assumes that UEs are able to find out what is the HO capability of a cell they are measuring. For example, a flag in the broadcast information of the cells telling the HO capability, or cells supporting selective handover are given certain range of PCIs, or the anchor communicates the HO capability of its neighbor cells to the UE via a new RRC message, etc...

For example, UEs can be asked to report cells that support selective handover earlier than those that don't support it (by having a lower threshold in A3, for example), as a more reliable signal level might be required from a neighbor to hand over a UE completely as compared to handing over only a sub set of the UE bearers.

According to some of the example embodiments, when a UE is connected to more than one cell, multiple measurement configuration parameters are set up for each cell that is serving the UE. This can be realized in several ways, such as:

- Use different value for the offset parameters such as *Ofn*, *Ocn*, *Ofp* and *Ocp* that are part of the *MeasObjectEUTRA* IE that is part of the measurement configuration setup. or/and
- Use different event thresholds for each serving cell, such as A3 offset and TTT, which are part of the *reportConfigEUTRA* IE.

According to some of the example embodiments, the anchor decides the values for these configuration parameters for all the serving cells.

According to some of the example embodiments, the booster sends out the configuration parameters to be used for its own cell that is going to be connected to the UE, and the anchor communicates this to the UE on behalf of the new booster that is being added.

According to some of the example embodiments, the serving cell to which a certain measurement configuration is applicable to are indicated explicitly in the measurement configuration messages. This can be done in several ways, for example:

- the PCI of the cell to which the measurement configuration applies to can be comprised as a new IE inside the *measConfig* IE.
- a numerical ID of increasing values is assigned for each serving cell of the UE (for example, 0 for the anchor, 1 for the first booster, 2 for the second booster, etc), and this ID is comprised as a new IE inside the *measConfig* IE. The IDs associated with each serving cell can be explicitly communicated when a booster is added to a UE, or it can be done implicitly by increasing the serving cell count simultaneously at the anchor and the UE.

According to some of the example embodiments, when a UE is connected to more than one cell and bearers are to be setup, modified or released with a booster cell, the anchor communicates this to the UE via an *RRConnectionReconfiguration* message (without *mobilityControlInfo*) that comprises an indication that the configurations comprised in the message are for a booster connection, rather than the anchor. A new IE could be introduced in the message to indicate the booster cell by using the PCI of the booster cell, or another agreed upon ID that is known to both the UE and the anchor as described above. The concerned bearers are indicated in *drb-ToAddModList* and/or *drb-ToReleaseList* IEs in the *radioResourceConfigDedicated* IE) and the UE applies the settings there on the protocol stack of the indicated booster link. The UE can find out that the *RRConnectionReconfiguration* message is intended for the anchor link if the message doesn't comprise the booster indicator IE or the value of it set to the ID (PCI or another agreed upon ID) of the anchor cell.

According to some of the example embodiments, when a UE is connected to more than one cell and bearers are to be setup, modified or released with a booster cell and also anchor cell, the anchor communicates this to the UE via an *RRConnectionReconfiguration* (without *mobilityControlInfo*) message that comprises an explicit indication to the link that the bearers are corresponding to. A new IE could be introduced in the *drb-ToAddModList* and/or *drb-ToReleaseList* IEs, with the value to be set to the PCI of the relevant cell or another agreed upon ID that is known to both the UE and the anchor as described above. The UE can find out that the bearer to be setup, modified or released are on the anchor link either if the new indicator IE is not comprised in the *drb-ToAddModList* and/or *drb-ToReleaseList*s, or if its value is set to the ID (PCI or another agreed upon ID) of the anchor cell.

According to some of the example embodiments, bearers could be handed over to a booster link, after the completion of a selective handover (referred to as subsequent selective handover from here onwards). There are several ways of communicating this to the UE:

- Using the same messaging structure as a selective handover, which the UE can recognize as a subsequent handover because it already has a link established with the cell indicated in the target PCI comprised in the *mobilityControlInfo* IE.

- Using similar messaging structure as a selective handover but excluding information such as *mobilityControlInfo* that is not needed now as the UE is already connected to the booster, but using the following two additional IEs:
 - A booster indicator IE (similar to the bearer setup/modification/release procedure described above)
 - A selective HO indicator IE (to differentiate it from the bearer setup/modification/release procedure described above)

According to some of the example embodiments, when a UE gets a subsequent selective handover command, it performs similar operations as in a selective handover discussed above apart from the procedures a, b and c as the UE is already synchronized to the target, have the C-RNTI from the target and has already initialized the protocol stack corresponding to the booster link.

An LTE system has been assumed throughout the discussion of the example embodiments presented herein. However, most of the ideas discussed above can become readily applicable to mobile broadband systems such as High Speed Packet Access (HSPA).

6 Example advantages of the example embodiments

The example embodiments presented herein make it possible to perform handovers selectively between a source and a target eNB, thereby creating more system flexibility than the legacy way of performing handover where a UE is completely handed over to the target. Some advantages of this are:

- Possibility to keep all the UE bearers ongoing as the bearers that the target was not able to admit can be kept at the source
- Possibility to trigger handover at a bearers level rather than at UE level. For example, the source eNB can keep the bearers that can't tolerate discontinuity such as VoIP services with itself until the radio conditions of the source are at much lower quality than the target, while bearers that are very capacity hungry but more tolerant to interruptions such as file download can be handed over to the target even if the radio conditions at the source are not that bad.
- Possibility to maintain control plane at one eNB, while sharing the data load at several eNBs. This opens several opportunities such as network sharing. For example, several operators can share the pico nodes for data bearers, while maintaining the signaling radio bearers only at their macros.
- Control plane diversity, such as sending of handover command from the source and/or targets or sending of the measurement report towards targets becomes rather straightforward with multiple connectivity.
- RLF on the booster or anchor node can be recovered faster. Booster recovery is straightforward as the UE context resides at the anchor, and anchor recovery also becomes fast as the booster can fetch the context easily from the network.

7 Figures

7.1 Example node configurations

The following example nodes may be configured to perform the example operations discussed herein.

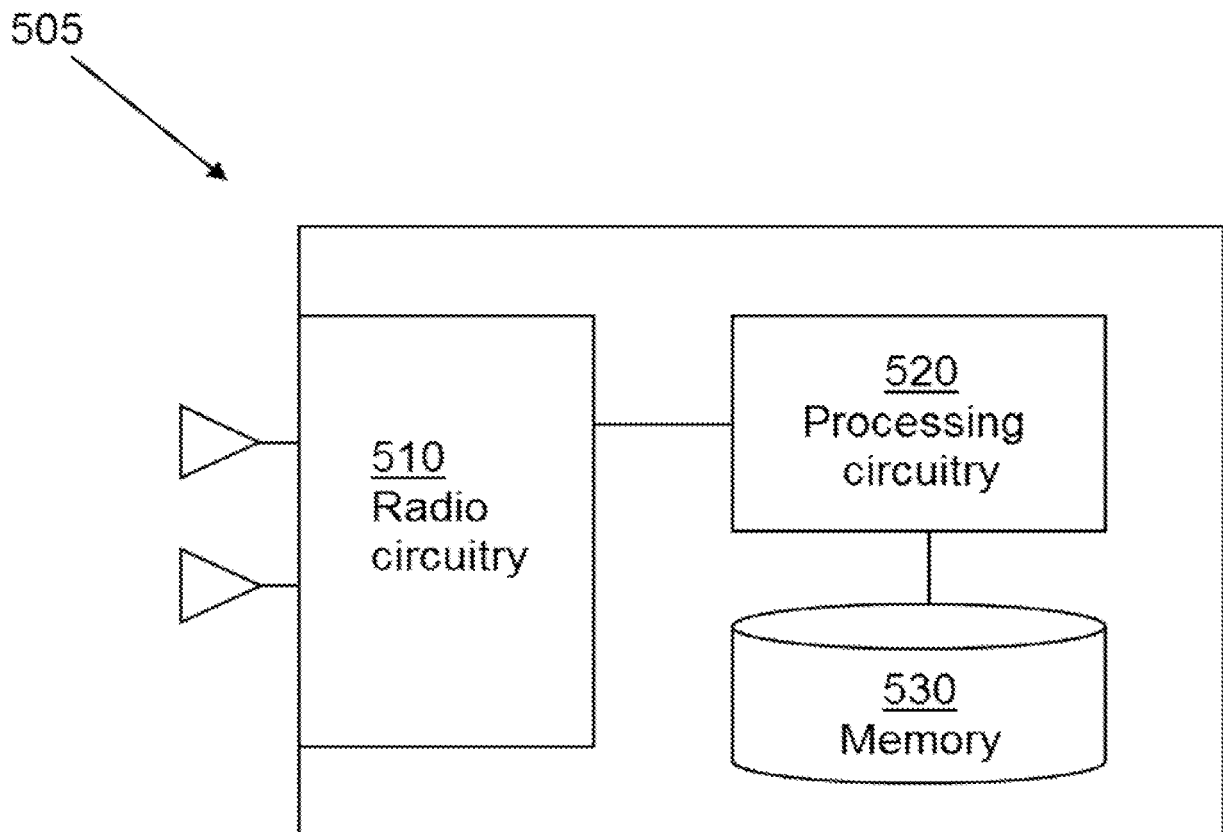


Figure 16 – example user equipment configuration

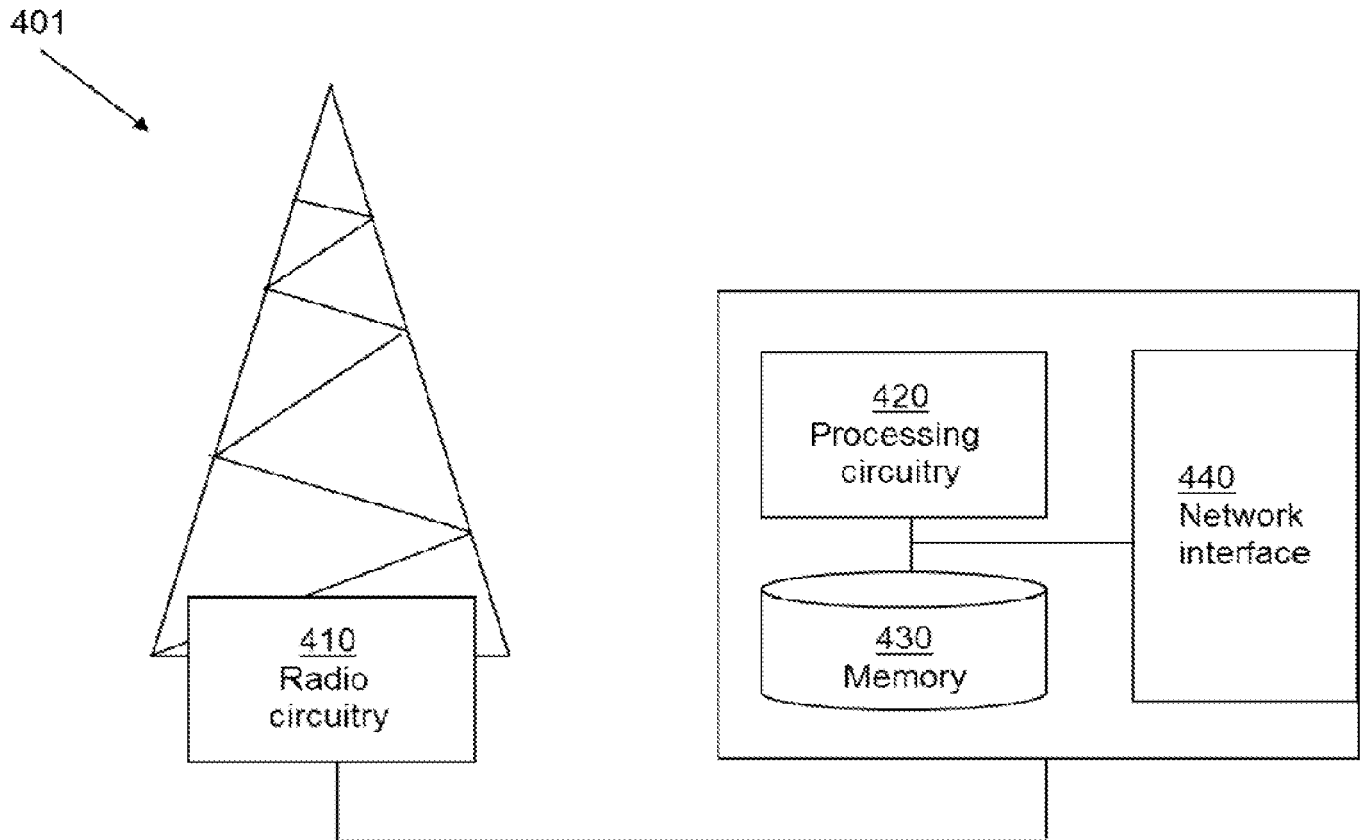


Figure 17 – Example base station configuration

The example embodiments presented herein may be utilized in a wireless network, which may further comprise a base station 401, as illustrated in Figure 17. The wireless network may also comprise a user equipment 505, as illustrated in 16. It should be appreciated that the examples provided in Figures 16 and 17 are shown merely as non-limiting examples.

As shown in Figure 17, the example base station 401 may comprise processing circuitry 420, a memory 430, radio circuitry 410, and at least one antenna. The processing circuitry 420 may comprise RF circuitry and baseband processing circuitry (not shown). In particular embodiments, some or all of the functionality described above as being provided by a mobile base station, a base station controller, a relay node, a NodeB, an enhanced NodeB, and/or any other type of mobile communications node may be provided by the processing circuitry 420 executing instructions stored on a computer-readable medium, such as the memory 430 shown in Figure 17.

Alternative embodiments of the base station 401 may comprise additional components responsible for providing additional functionality, comprising any of the functionality identified above and/or any functionality necessary to support the solution described above. In other example embodiments, a network node may be not equipped with a radio interface or radio circuitry 410.

It should also be appreciated that the processing circuitry (or any other hardware and/or software unit configured to execute operations and/or commands) of the base station 401 illustrated in Figure 17 may be configured to configure to provide a selective handover procedure. It should also be appreciated that the example base station of Figure 17 may be a source and/or target base station.

According to some of the example embodiments, the source base station may be functioning as either a booster or anchor node, while the target base station may also function as either a booster or anchor node. Thus, according to some of the example embodiments, the selective handover procedure may take place from an anchor (source) to a booster (target) node, from a booster (source) node to another booster (target) node, or from a booster (source) node to an anchor (target) node.

An example of a user equipment is provided in Figure 16. The example user equipment 505 may comprise processing circuitry 520, a memory 530, radio circuitry 510, and at least one antenna. The radio circuitry may comprise RF circuitry and baseband processing circuitry (not shown). In particular embodiments, some or all of the functionality described above as being provided by mobile communication devices or other forms of wireless device may be provided by the processing circuitry 520 executing instructions stored on a computer-readable medium, such as the memory 530 shown in Figure 16.

Alternative embodiments of the user equipment 505 may comprise additional components responsible for providing additional functionality, comprising any of the functionality identified above and/or any functionality necessary to support the example embodiments described herein.

It should be appreciated that the processing circuitry (or any other hardware and/or software unit configured to execute operations and/or commands) of the user equipment may be configured to provide selective handover procedures.

7.2 Flow diagrams

It should be appreciated that the terms 'source base station' and 'target base station' have been used to describe the example embodiments herein. It should be appreciated that the source and target in general may be thought of as cells. However, it is the base stations which send the messages described herein on behalf of their respective cells.

Figure 18 is a flow diagram depicting example operations which may be taken by a user equipment 505 of Figure 16 in the providing a handover of at least a sub-set of bearers associated with a user equipment. It should also be appreciated that Figure 18 comprises some operations which are illustrated with a darker border and some operations which are illustrated with a lighter border. The operations which are comprised in a darker border are operations which are comprised in the broadest example embodiment. The operations which are comprised in a lighter border are example embodiments which may be comprised in, or a part of, or are further operations which may be taken in addition to the operations of the boarder example embodiments. It should be appreciated that these operations need not be performed in order. Furthermore, it should be appreciated that not all of the operations need to be performed. The example operations may be performed in any order and in any combination.

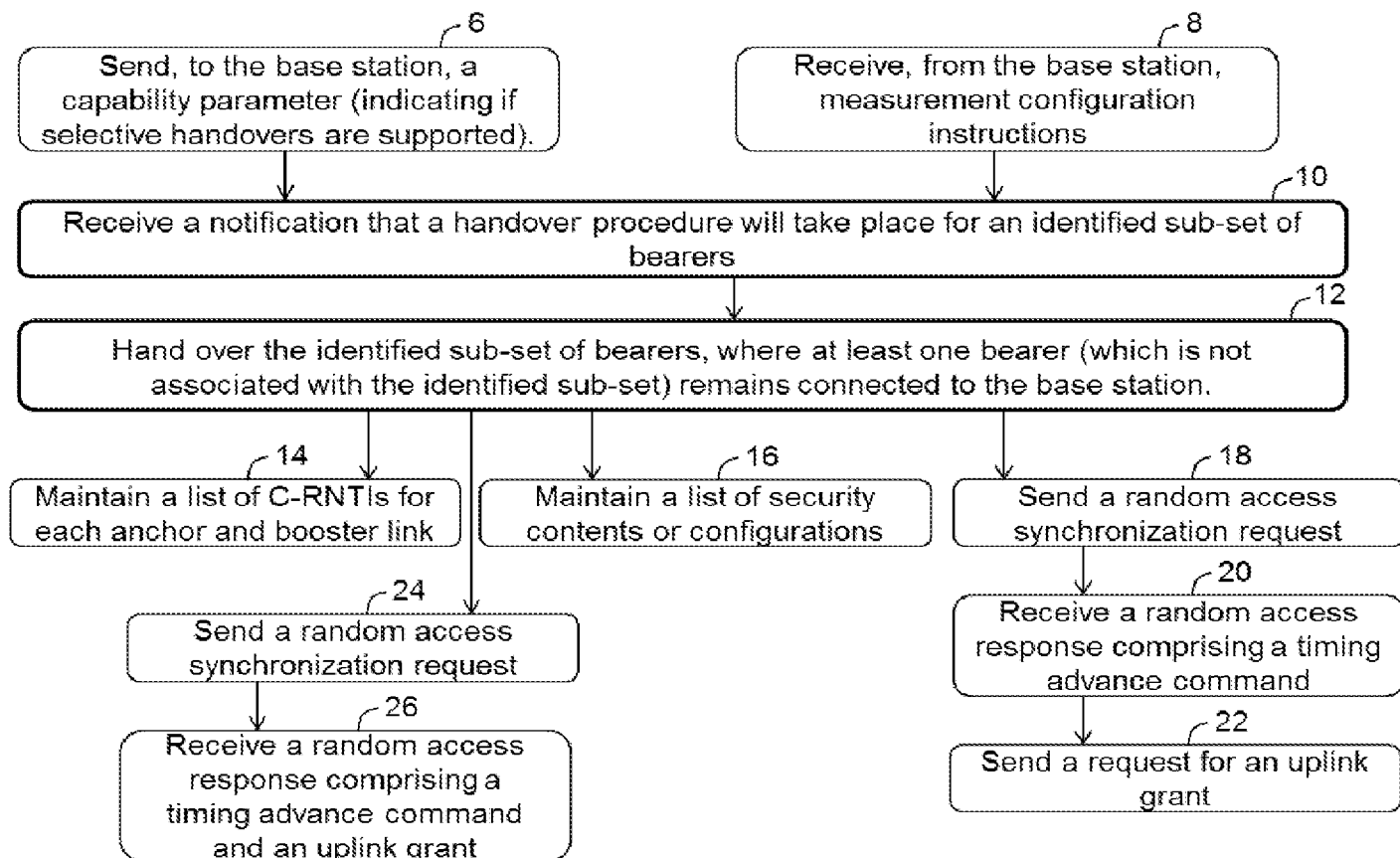


Figure 18 – example operations of a user equipment

Figure 19 is a flow diagram depicting example operations which may be taken by the base station 401 of Figure 17 in the providing a handover of at least a sub-set of bearers associated with a user equipment. It should also be appreciated that Figure 19 comprises some operations which are illustrated with a darker border and some operations which are illustrated with a lighter border. The operations which are comprised in a darker border are operations which are comprised in the broadest example embodiment. The operations which are comprised in a lighter border are example embodiments which may be comprised in, or a part of, or are further operations which may be taken in addition to the operations of the boarder example embodiments. It should be appreciated that these operations need not be performed in order. Furthermore, it should be appreciated that not all of the operations need to be performed. The example operations may be performed in any order and in any combination.

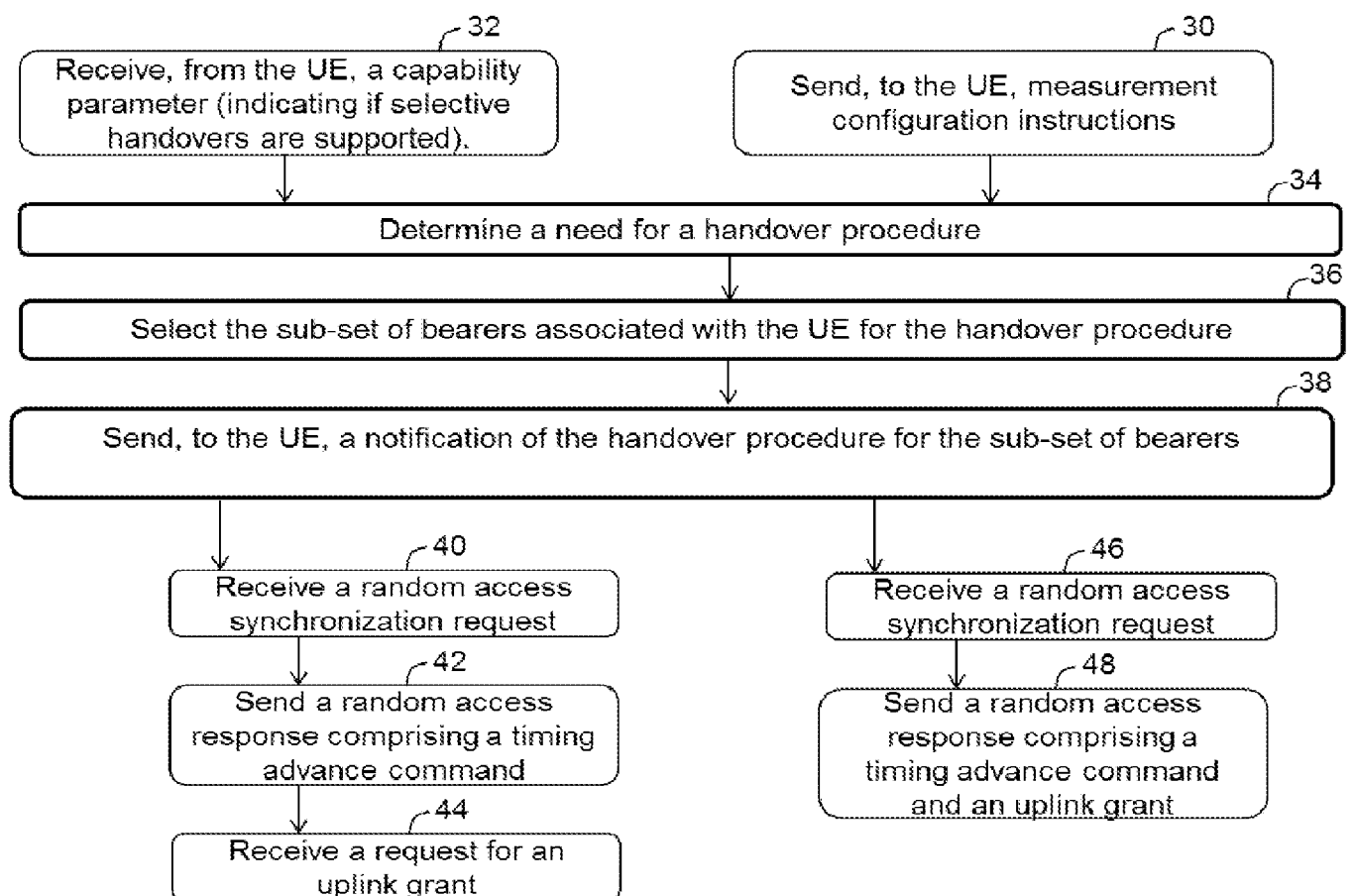


Figure 19 – example operations of a base station

8 Conclusion

It should be noted that although terminology from 3GPP LTE has been used herein to explain the example embodiments, this should not be seen as limiting the scope of the example embodiments to only the aforementioned system. Other wireless systems, comprising WCDMA, WiMax, UMB, WiFi and GSM, may also benefit from the example embodiments disclosed herein.

The description of the example embodiments provided herein have been presented for purposes of illustration. The description is not intended to be exhaustive or to limit example embodiments to the precise form disclosed, and modifications and variations are possible in light of the above teachings or may be acquired from practice of various alternatives to the provided embodiments. The examples discussed herein were chosen and described in order to explain the principles and the nature of various example embodiments and its practical application to enable one skilled in the art to utilize the example embodiments in various manners and with various modifications as are suited to the particular use contemplated. The features of the embodiments described herein may be combined in all possible combinations of methods, apparatus, modules, systems, and computer program products. It should be appreciated that the example embodiments presented herein may be practiced in any combination with each other.

It should be noted that the word “comprising” does not necessarily exclude the presence of other elements or steps than those listed and the words “a” or “an” preceding an element do not exclude the presence of a plurality of such elements. It should further be noted that any reference signs do not limit the scope of the claims, that the example embodiments may be implemented at least in part by means of both hardware and software, and that several “means”, “units” or “devices” may be represented by the same item of hardware.

Also note that terminology such as user equipment should be considered as non-limiting. A device or user equipment as the term is used herein, is to be broadly interpreted to comprise a radiotelephone having ability for Internet/intranet access, web browser, organizer, calendar, a camera (e.g., video and/or still image camera), a sound recorder (e.g., a microphone), and/or global positioning system (GPS) receiver; a personal communications system (PCS) user equipment that may combine a cellular radiotelephone with data processing; a personal digital assistant (PDA) that can comprise a radiotelephone or wireless communication system; a laptop; a camera (e.g., video and/or still image camera) having communication ability; and any other computation or communication device capable of transceiving, such as a personal computer, a home entertainment system, a television, etc. It should be appreciated that the term user equipment may also comprise any number of connected devices.

The various example embodiments described herein are described in the general context of method steps or processes, which may be implemented in one aspect by a computer program product, embodied in a computer-readable medium, comprising computer-executable instructions, such as program code, executed by computers in networked environments. A computer-readable medium may comprise removable and non-removable storage devices comprising, but not limited to, Read Only Memory (ROM), Random Access Memory (RAM), compact discs (CDs), digital versatile discs (DVD), etc. Generally, program modules may comprise routines, programs, objects, components, data structures, etc. that perform particular tasks or implement particular abstract data types. Computer-executable instructions, associated data structures, and program modules represent examples of program code for executing steps of the methods disclosed herein. The particular sequence of such executable instructions or associated data structures represents examples of corresponding acts for implementing the functions described in such steps or processes.

In the drawings and specification, there have been disclosed exemplary embodiments. However, many variations and modifications can be made to these embodiments. Accordingly, although specific terms are employed, they are used in a generic and descriptive sense only and not for purposes of limitation, the scope of the embodiments being defined by the following summary of example embodiments.

9 Abbreviations

3GPP	3 rd Generation Partnership Project
AMBR	Aggregate Maximum Bit Rate
AP	Application Protocol
ARP	Allocation and Retention Priority
ARQ	Automatic Repeat reQuest
BCH	Broadcast Channel
CIO	Cell Individual Offset
CN	Core Network
CRS	Cell specific Reference Symbol
CSG	Closed Subscriber Group
DL	Downlink
DM	Demodulation
DRB	Data Radio Bearer
E-UTRAN	Evolved UMTS Terrestrial Radio Access Network
eNB/eNodeB	enhanced Node B(base station)
EPC	Evolved Packet Core
EPS	Evolved Packet System
GBR	Guaranteed Bit Rate
GUMMEI	Globally Unique Mobility Management Entity Identifier

HARQ	Hybrid Automatic Repeat reQuest
HeNB	Home eNB
HO	Handover
HOM	Handover Margin
HSPA	High-Speed Packet Access
IE	Information Element
ID	Identity
IP	Internet Protocol
LTE	Long Term Evolution
MAC	Medium Access Control
MBR	Maximum Bit Rate
MME	Mobility Management Entity
MTCP	Multi-path Transmission Control Protocol
NAS	Non-Access Stratum
OAM	Operation and Maintenance
P-GW	PDN Gateway
PBCH	Physical Broadcast CHannel
PCell	Primary Cell
PCFICH	Physical Control Format Indicator CHannel
PCI	Physical Cell Identity
PDCCH	Physical Downlink Control CHannel
PDCCP	Packet Data Convergence Protocol
PDN	Packet Data Network
PDSCH	Physical Downlink Shared CHannel
PDU	Packet Data Unit
PHICH	Physical Hybrid ARQ Indicator CHannel
PSS	Primary Synchronization Signal
QCI	QoS Class Identifier
QoS	Quality of Service
RLC	Radio Link Control
RAB	Radio Access Bearer
RAT	Radio Access Technology
RE	Resource Element
RRC	Radio Resource Control
RRH	Remote Radio Head
RRM	Radio Resource Management
RS	Reference Signal
RSCP	Received Signal Code Power
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality

S-GW	Serving Gateway
SCell	Secondary Cell
SCTP	Stream Control Transmission Protocol
SDF	Service Data Flow
SDU	Service Data Unit
SRB	Signaling Radio Bearer
SRVCC	Single Radio Voice Call Continuity
SSS	Secondary Synchronization Signal
TCP	Transmission Control Protocol
TTT	Time To Trigger
UE	User Equipment
UL	Uplink
VoIP	Voice over Internet Protocol

10 Summary of example embodiments

In some instances, the summary of example embodiments provides specific names for messages and information elements which are passed throughout the network. It should be appreciated that such names are used merely as an examples. One purpose of the summary of example embodiments is to highlight the function of such messages and information elements. It should further be appreciated that any messages mentioned herein may be applied to any new or existing interface of the wireless network.

1. A method, in a user equipment, for a handover of a sub-set of bearers associated with the user equipment, the method comprising:
 - receiving **(10)**, from a base station, a notification that a handover procedure will take place for an identified sub-set of bearers; and
 - handing over **(12)** the identified sub-set of bearers, wherein at least one bearer associated with the user equipment, which is not part of the identified sub-set of bearers, remains connected to the base station.
2. The method of example embodiment 1, wherein the base station is a source base station or a target base station.
3. The method of any of example embodiments 1-2, wherein the base station is an anchor or a booster node.
4. The method of any of example embodiments 1-3, wherein the sub-set of bearers is an empty sub-set of bearers.

According to some of the example embodiments, the empty sub-set of bearers may allow for the synchronization of the user equipment to the target base station, thus allowing for the possibility of transmitting future mobility signalling from both the serving and target cell.

5. The method of any of example embodiments 1-4, further comprising sending (6), to the base station, a capability parameter, said capability parameter providing an indication of whether or not the user equipment supports selective handover procedures.

6. The method of any of example embodiments 1-4, wherein the notification does not comprise a *srb-ToAddModList* entry or such entry is empty.

According to some of the example embodiments, this may provide an indication to the user equipment that the handover procedure is a selective handover procedure.

According to some of the example embodiments, the notification may also, or alternatively, comprise a new information element for selective handover indication in the *mobilityControlInfo* IE. It should be appreciated that this IE may take different values depending on the type of selective handover that is being requested (e.g., different values for a handover of data bearers and signalling radio bearers).

According to some of the example embodiments, the selective handover may also be indicated to the user equipment by not comprising a *radioResourceConfigDedicated* IE in an *RRCCConnectionReconfiguration* message. According to some of the example embodiments, such an indication may be used for empty handovers.

7. The method of any of example embodiments 1-6, wherein the base station is a source base station that is forwarding the notification on behalf of the target base station.

According to some of the example embodiments, the target may send a *RRCCConnectionReconfiguration* message to the source base station via a target to source information element of a handover request acknowledgement.

It should also be appreciated that the base station may be a target base station sending the notification.

8. The method of any of example embodiments 1-7, further comprising performing the following steps upon receiving a *RRCCConnectionReconfiguration* message:

- a. Start synchronizing to the downlink of the target cell.
- b. Add the indicated C-RNTI to the list of C-RNTIs being used and associate it with the target cell (e.g. using the target cell's PCI)
- c. Initializes a new protocol stack that corresponds with the target cell and configures the MAC and PHY layers by applying default configurations as well as on the configurations indicated in the *radioResourceConfigCommon* and other relevant IEs of the *mobilityControlInfo*.
- d. Release all the DRBs comprised in the *drb-ToReleaseList* (which comprises releasing

the associated PDCP, RLC entities and DTCH logical channel)

- e. Establish the PDCP, RLC and DTCH for all the DRBs in the *drb-ToAddModList* in the newly configured protocol stack that is associated with the target cell, using the protocol configurations comprised in the list and for the PDCP, additionally utilizing the new security configurations.
 - f. Transfer any outstanding PDCP SDUs (i.e. those that are in the retransmission buffer of the anchor) of all the DRBs in the *drb-ToAddModList* to which lossless handover is applicable to the corresponding new PDCP entities that are setup in the previous step.
 - g. Release all the DRBs comprised in the *drb-ToAddModList* (which comprises releasing the associated PDCP, RLC entities and DTCH logical channel) from the source protocol stack
 - h. If the *srb-ToAddModList* is comprised and not empty, which indicates the switching of the anchor, then setup the SRBs in the new protocol stack by applying the default SRB configurations as well as establishing the PDPC (if needed, and if so applying the new security settings), RLC and DCCH based on the configurations comprised in the in the *srb-ToAddModList*) and release the SRBs from the protocol stack associated with the source.
9. The method of any of example embodiments 1-8, further comprising maintaining **(14)** a list of C-RNTIs for each anchor and booster link.
10. The method of any of example embodiments 1-9, further comprising maintaining **(16)** a list of security contexts or configurations, each context or configuration corresponding to a different anchor or booster link.
11. The method of any of example embodiments 1-10, further comprising sending **(18)**, to a target base station, a random access synchronization request, wherein the handover procedure results in an adding of a booster.
- According to some of the example embodiments, the target may reply to the random access synchronization request without an UL grant.
12. The method of example embodiment 11, further comprising receiving **(20)**, from the target base station, a random access response, said response comprising a timing advance command.

13. The method of example embodiment 12, further comprising sending **(22)**, to the target base station, a request for an uplink grant. According to some of the example embodiments, such a request may be made if the user equipment did not have enough resources to transmit a *RRCCConnectionReconfigurationComplete* message towards the anchor.
14. The method of any of example embodiments 1-10, further comprising sending **(24)**, to a target base station, a random access synchronization request, wherein the handover procedure results in a switching of an anchor.
15. The method of example embodiment 14, further comprising receiving **(26)**, from the target base station, a random access response, said response comprising a timing advance command and an uplink grant.
16. The method of any of example embodiments 1-15, further comprising receiving **(8)**, from the base station, configuration instructions for performing measurements, said instructions comprising triggering events such that once a triggering event is fulfilled results of the measurements are sent to an anchor or the base station.

According to some of the example embodiments, an example of such a triggering event may be a user equipment buffer level rising above a predefined threshold level.
17. The method of example embodiment 16, wherein the configuration instructions further comprises multiple sets of measurement instructions.

According to some of the example embodiments, some of the measurement instructions may be applicable to all cells where some may only be applicable to cells that support selective handovers. Thus, the measurement instructions may further comprises an information element providing an indication as to which cells support selective handover. According to some of the example embodiments, a numerical ID or a PCI of a cell may be used to identify the different cells and corresponding measurement configurations.
18. The method of any of example embodiments 16-17, wherein the measurement instructions comprise a plurality of measurement parameters or threshold values, each cell which is serving the user equipment being associated with a set of measurement parameters or threshold values.
19. The method of any of example embodiments 16-18, wherein the measurement configurations for all serving cells are sent from an anchor base station.

20. The method of any of example embodiments 16-18, wherein a booster base station sends instructions with respect to a cell associated with the booster base station.

According to some of the example embodiments, the booster base station may also send such instructions to the anchor base station which forwards the instructions to the user equipment on behalf of the booster.

21. The method of any of example embodiments 1-20, wherein the notification is sent from an anchor base station and the handover procedure is solely or also with respect to a booster base station, wherein the notification is an *RRCConnectionReconfiguration* message comprising an indication the notification is solely or also for a booster base station.

It should be appreciated that the above may occur when a user equipment is connected to more than one cell or link.

According to some of the example embodiments, this may be indicated with the use of an information element or a PCI of the booster and all the bearers to be setup/modified/released in the booster.

According to some of the example embodiments, this may comprise communicating information about the bearers to be setup/modified/released in both the anchor and booster. This may be indicated by providing for each bearer the PCI of the cell to which the bearer belongs to.

22. The method of any of example embodiments 1-21, wherein the handover procedure is a subsequent selective handover procedure, where the user equipment has a pre-existing link established with a cell identified in the notification.

23. A user equipment, for a handover of a sub-set of bearers associated with the user equipment, the user equipment comprising:

radio circuitry **(510)** configured to receive, from a base station, a notification that a handover procedure will take place for an identified sub-set of bearers; and

processing circuitry **(520)** configured to delete the identified sub-set of bearers, wherein at least one bearer associated with the user equipment, which is not part of the identified sub-set of bearers, remains connected to the base station.

It should be appreciated that, according to some of the example embodiments, all of the bearers associated with a user equipment (both SRB and DRBs) may be handed over. In such an instance the base station to which the bearers are being handed over will be the new anchor while the old anchor (where the bearers are being handed over from) will still be connected.

24. The user equipment of example embodiment 23, wherein the base station is a source base station or a target base station.

25. The user equipment of any of example embodiments 23-24, wherein the base station is an anchor or a booster node.

26. The user equipment of any of example embodiments 23-25, wherein the sub-set of bearers is an empty sub-set of bearers.

According to some of the example embodiments, the empty sub-set of bearers may allow for the synchronization of the user equipment to the target base station, thus allowing for the possibility of transmitting future mobility signalling from both the serving and target cell.

27. The user equipment of any of example embodiments 23-26, wherein the radio circuitry (510) is further configured to send, to the base station, a capability parameter, said capability parameter providing an indication of whether or not the user equipment supports selective handover procedures.

28. The user equipment of any of example embodiments 23-26, wherein the notification does not comprise a *srb-ToAddModList* entry or such entry is empty.

According to some of the example embodiments, this may provide an indication to the user equipment that the handover procedure is a selective handover procedure.

According to some of the example embodiments, the notification may also, or alternatively, comprise a new information element for selective handover indication in the *mobilityControlInfo* IE. It should be appreciated that this IE may take different values depending on the type of selective handover that is being requested (e.g., different values for a handover of data bearers and signalling radio bearers).

According to some of the example embodiments, the selective handover may also be indicated to the user equipment by not comprising a *radioResourceConfigDedicated* IE in an *RRCCConnectionReconfiguration* message. According to some of the example embodiments, such an indication may be used for empty handovers.

29. The user equipment of any of example embodiments 23-28, wherein the base station is a source base station that is forwarding the notification on behalf of the target base station.

According to some of the example embodiments, the target may send a *RRCCConnectionReconfiguration* message to the source base station via a target to source information element of a handover request acknowledgement.

It should also be appreciated that the base station may be a target base station sending the notification.

30. The user equipment of any of example embodiments 23-29, wherein the processing circuitry (520) is further configured to perform the following steps upon receiving a *RRConnectionReconfiguration* message:
- a. Start synchronizing to the downlink of the target cell.
 - b. Add the indicated C-RNTI to the list of C-RNTIs being used and associate it with the target cell (e.g. using the target cell's PCI)
 - c. Initializes a new protocol stack that corresponds with the target cell and configures the MAC and PHY layers by applying default configurations as well as on the configurations indicated in the *radioResourceConfigCommon* and other relevant IEs of the *mobilityControlInfo*.
 - d. Release all the DRBs comprised in the *drb-ToReleaseList* (which comprises releasing the associated PDCP, RLC entities and DTCH logical channel)
 - e. Establish the PDCP, RLC and DTCH for all the DRBs in the *drb-ToAddModList* in the newly configured protocol stack that is associated with the target cell, using the protocol configurations comprised in the list and for the PDCP, additionally utilizing the new security configurations.
 - f. Transfer any outstanding PDCP SDUs (i.e. those that are in the retransmission buffer of the anchor) of all the DRBs in the *drb-ToAddModList* to which lossless handover is applicable to the corresponding new PDCP entities that are setup in the previous step.
 - g. Release all the DRBs comprised in the *drb-ToAddModList* (which comprises releasing the associated PDCP, RLC entities and DTCH logical channel) from the source protocol stack
 - h. If the *srb-ToAddModList* is comprised and not empty, which indicates the switching of the anchor, then setup the SRBs in the new protocol stack by applying the default SRB configurations as well as establishing the PDPC (if needed, and if so applying the new security settings), RLC and DCCH based on the configurations comprised in the in the *srb-ToAddModList*) and release the SRBs from the protocol stack associated with the source.
31. The user equipment of any of example embodiments 23-30, wherein the processing circuitry (520) is further configured to maintain a list of C-RNTIs for each anchor and booster link.

32. The user equipment of any of example embodiments 23-31, wherein the processing circuitry **(520)** is further configured to maintain a list of security contexts or configurations, each context or configuration corresponding to a different anchor or booster link.

33. The user equipment of any of example embodiments 23-32, wherein the radio circuitry **(510)** is further configured to send, to a target base station, a random access synchronization request, wherein the handover procedure results in an adding of a booster.

According to some of the example embodiments, the target base station may respond to the random access synchronization request without sending an UL grant.

34. The user equipment of example embodiment 33, wherein the radio circuitry **(510)** is further configured to receive, from the target base station, a random access response, said response comprising a timing advance command.

35. The user equipment of example embodiment 34, wherein the radio circuitry **(510)** is further configured to send, to the target base station, a request for an uplink grant.

According to some of the example embodiments, such a request may be made if the user equipment did not have enough resources to transmit a *RRCConnectionReconfigurationComplete* message towards the anchor.

36. The user equipment of any of example embodiments 23-32, wherein the radio circuitry **(510)** is further configured to send, to a target base station, a random access synchronization request, wherein the handover procedure results in a switching of an anchor.

37. The user equipment of example embodiment 36, wherein the radio circuitry **(510)** is further configured to receive, from the target base station, a random access response, said response comprising a timing advance command and an uplink grant.

38. The user equipment of any of example embodiments 23-37, wherein the radio circuitry **(510)** is further configured to receive, from the base station, configuration instructions for performing measurements, said instructions comprising triggering events such that once a triggering event is fulfilled results of the measurements are sent to an anchor or the base station.

According to some of the example embodiments, an example of such a triggering event may be a user equipment buffer level rising above a predefined threshold level.

39. The user equipment of example embodiment 38, wherein the configuration instructions further comprises multiple sets of measurement instructions.

According to some of the example embodiments, some of the measurement instructions may be applicable to all cells where some may only be applicable to cells that support selective handovers. Thus, the measurement instructions may further comprises an information element providing an indication as to which cells support selective handover. According to some of the example embodiments, a numerical ID or a PCI of a cell may be used to identify the different cells and corresponding measurement configurations.

40. The user equipment of any of example embodiments 38-39, wherein the measurement instructions comprise a plurality of measurement parameters or threshold values, each cell which is serving the user equipment being associated with a set of measurement parameters or threshold values.
41. The user equipment of any of example embodiments 38-40, wherein the measurement configurations for all serving cells are sent from an anchor base station.
42. The user equipment of any of example embodiments 38-41, wherein a booster base station sends instructions with respect to a cell associated with the booster base station. According to some of the example embodiments, the booster base station may also send such instructions to the anchor base station which forwards the instructions to the user equipment.
43. The user equipment of any of example embodiments 23-42, wherein the notification is sent from an anchor base station and the handover procedure is solely or also with respect to a booster base station, wherein the notification is an *RRCCConnectionReconfiguration* message comprising an indication the notification is solely or also for a booster base station.

It should be appreciated that the above may occur when a user equipment is connected to more than one cell or link.

According to some of the example embodiments, this may be indicated with the use of an information element or a PCI of the booster and all the bearers to be setup/modified/released in the booster.

According to some of the example embodiments, this may comprise communicating information about the bearers to be setup/modified/released in both the anchor and booster. This may be indicated by providing for each bearer the PCI of the cell to which the bearer belongs to.

44. The user equipment of any of example embodiments 23-43, wherein the handover procedure is a subsequent selective handover procedure, where the user equipment has a pre-existing link established with a cell identified in the notification.

45. A method, in a base station, for providing a handover of at least a sub-set of bearers associated with a user equipment, the method comprising:
- determining **(34)** a need for a handover procedure;
 - selecting **(36)** the sub-set of bearers associated with the user equipment for the handover procedure; and
 - sending **(38)**, to the user equipment, a notification of the handover procedure for the sub-set of bearers.
46. The method of example embodiment 45, wherein the base station is a source base station or a target base station.
47. The method of any of example embodiments 45-46, wherein the base station is an anchor or a booster node.
48. The method of any of example embodiments 45-47, wherein the sub-set of bearers is an empty sub-set of bearers.
- According to some of the example embodiments, the empty sub-set of bearers may allow for the synchronization of the user equipment to the target base station, thus allowing for the possibility of transmitting future mobility signalling from both the serving and target cell.
49. The method of any of example embodiments 45-48, further comprising receiving **(32)**, from the user equipment, a capability parameter, said capability parameter providing an indication of whether or not the user equipment supports selective handover procedures.
50. The method of any of example embodiments 45-49, wherein the notification does not comprise a *srb-ToAddModList* entry or such entry is empty.
- According to some of the example embodiments, this may provide an indication to the user equipment that the handover procedure is a selective handover procedure.
- According to some of the example embodiments, the notification may also, or alternatively, comprise a new information element for selective handover indication in the *mobilityControlInfo* IE. It should be appreciated that this IE may take different values depending on the type of selective handover that is being requested (e.g., different values for a handover of data bearers and signalling radio bearers).
- According to some of the example embodiments, the selective handover may also be indicated to the user equipment by not comprising a *radioResourceConfigDedicated* IE in an *RRCCConnectionReconfiguration* message. According to some of the example embodiments, such an indication may be used for empty handovers.

51. The method of any of example embodiments 45-50, wherein the base station is a source base station that is forwarding the notification on behalf of the target base station.

According to some of the example embodiments, the target may send a *RRConnectionReconfiguration* message to the source base station via a target to source information element of a handover request acknowledgement.

It should also be appreciated that the base station may be a target base station sending the notification.

52. The method of any of example embodiments 45-51, further comprising receiving **(40)**, from the user equipment, a random access synchronization request, wherein the handover procedure results in an adding of a booster.

According to some of the example embodiments, the target may reply to the random access synchronization request without an UL grant.

53. The method of example embodiment 52, further comprising sending **(42)**, to the user equipment, a random access response, said response comprising a timing advance command.

54. The method of example embodiment 53, further comprising receiving **(44)**, from the user equipment, a request for an uplink grant.

According to some of the example embodiments, such a request may be made if the user equipment did not have enough resources to transmit a *RRConnectionReconfigurationComplete* message towards the anchor.

55. The method of any of example embodiments 45-51, further comprising receiving **(46)**, from the user equipment, a random access synchronization request, wherein the handover procedure results in a switching of an anchor.

56. The method of example embodiment 55, further comprising sending **(48)**, to the user equipment, a random access response, said response comprising a timing advance command and an uplink grant.

57. The method of any of example embodiments 45-51, further comprising sending **(30)**, to the user equipment, configuration instructions for performing measurements, said instructions comprising triggering events such that once a triggering event is fulfilled results of the measurements are sent to an anchor or the base station.

According to some of the example embodiments, an example of such a triggering event may be a user equipment buffer level rising above a predefined threshold level.

58. The method of example embodiment 57, wherein the configuration instructions further comprises multiple sets of measurement instructions.

According to some of the example embodiments, some of the measurement instructions may be applicable to all cells where some may only be applicable to cells that support selective handovers. Thus, the measurement instructions may further comprises an information element providing an indication as to which cells support selective handover. According to some of the example embodiments, a numerical ID or a PCI of a cell may be used to identify the different cells and corresponding measurement configurations.

59. The method of any of example embodiments 57-58, wherein the measurement instructions comprise a plurality of measurement parameters or threshold values, each cell which is serving the user equipment being associated with a set of measurement parameters or a threshold value.

60. The method of any of example embodiments 57-59, wherein the base station is a booster base station and sends instructions with respect to a cell associated with the booster base station.

According to some of the example embodiments, the booster base station may also send such instructions to the anchor base station which forwards the instructions to the user equipment on behalf of the booster.

61. The method of any of example embodiments 45-60, wherein the base station is an anchor base station and the notification is sent from the anchor base station and the handover procedure is solely or also with respect to a booster base station, wherein the notification is an *RRCCConnectionReconfiguration* message comprising an indication the notification is solely or also for a booster base station.

It should be appreciated that the above may occur when a user equipment is connected to more than one cell or link.

According to some of the example embodiments, this may be indicated with the use of an information element or a PCI of the booster and all the bearers to be setup/modified/released in the booster.

According to some of the example embodiments, this may comprise communicating information about the bearers to be setup/modified/released in both the anchor and booster. This may be indicated by providing for each bearer the PCI of the cell to which the bearer belongs to.

62. The method of any of example embodiments 45-61, wherein the handover procedure is a subsequent selective handover procedure, where the user equipment has a pre-existing link established with a cell identified in the notification.
63. A base station for providing a handover of at least a sub-set of bearers associated with a user equipment, the base station comprising:
processing circuitry **(420)** configured to determine a need for a handover procedure;
the processing circuitry **(420)** further configured to select the sub-set of bearers associated with the user equipment for the handover procedure; and
radio circuitry **(410)** configured to send, to the user equipment, a notification of the handover procedure for the sub-set of bearers.
64. The base station of example embodiment 63, wherein the base station is a source base station or a target base station.
65. The base station of any of example embodiments 63-64, wherein the base station is an anchor or a booster node.
66. The base station of any of example embodiments 63-65, wherein the sub-set of bearers is an empty sub-set of bearers.
According to some of the example embodiments, the empty sub-set of bearers may allow for the synchronization of the user equipment to the target base station, thus allowing for the possibility of transmitting future mobility signalling from both the serving and target cell.
67. The base station of any of example embodiments 63-66, wherein the radio circuitry **(410)** is further configured to receive, from the user equipment, a capability parameter, said capability parameter providing an indication of whether or not the user equipment supports selective handover procedures.
68. The base station of any of example embodiments 63-67, wherein the notification does not comprise a *srb-ToAddModList* entry or such entry is empty.
According to some of the example embodiments, this may provide an indication to the user equipment that the handover procedure is a selective handover procedure.
According to some of the example embodiments, the notification may also, or alternatively, comprise a new information element for selective handover indication in the *mobilityControlInfo* IE. It should be appreciated that this IE may take different values depending on the type of selective

handover that is being requested (e.g., different values for a handover of data bearers and signalling radio bearers).

According to some of the example embodiments, the selective handover may also be indicated to the user equipment by not comprising a *radioResourceConfigDedicated* IE in an *RRConnectionReconfiguration* message. According to some of the example embodiments, such an indication may be used for empty handovers.

69. The base station of any of example embodiments 63-68, wherein the base station is a source base station that is forwarding the notification on behalf of the target base station.

According to some of the example embodiments, the target may send a *RRConnectionReconfiguration* message to the source base station via a target to source information element of a handover request acknowledgement.

It should also be appreciated that the base station may be a target base station sending the notification.

70. The base station of any of example embodiments 63-69, wherein the radio circuitry **(410)** is further configured to receive, from the user equipment, a random access synchronization request, wherein the handover procedure results in an adding of a booster.

According to some of the example embodiments, the target may reply to the random access synchronization request without an UL grant.

71. The base station of example embodiment 70, wherein the radio circuitry **(410)** is further configured to send, to the user equipment, a random access response, said response comprising a timing advance command.

72. The base station of example embodiment 71, wherein the radio circuitry **(410)** is further configured to receive, from the user equipment, a request for an uplink grant.

According to some of the example embodiments, such a request may be made if the user equipment did not have enough resources to transmit a *RRConnectionReconfigurationComplete* message towards the anchor.

73. The base station of any of example embodiments 63-69, wherein the radio circuitry **(410)** is further configured to receive, from the user equipment, a random access synchronization request, wherein the handover procedure results in a switching of an anchor.

74. The base station of example embodiment 73, wherein the radio circuitry **(410)** is further configured to send, to the user equipment, a random access response, said response comprising a timing advance command and an uplink grant.

75. The base station of any of example embodiments 63-74, wherein the radio circuitry **(410)** is further configured to send, to the user equipment, configuration instructions for performing measurements, said instructions comprising triggering events such that once a triggering event is fulfilled results of the measurements are sent to an anchor or the base station.

According to some of the example embodiments, an example of such a triggering event may be a user equipment buffer level rising above a predefined threshold level.

76. The base station of example embodiment 75, wherein the configuration instructions further comprises multiple sets of measurement instructions.

According to some of the example embodiments, some of the measurement instructions may be applicable to all cells where some may only be applicable to cells that support selective handovers. Thus, the measurement instructions may further comprises an information element providing an indication as to which cells support selective handover. According to some of the example embodiments, a numerical ID or a PCI of a cell may be used to identify the different cells and corresponding measurement configurations.

77. The base station of any of example embodiments 75-76, wherein the measurement instructions comprise a plurality of measurement parameters or threshold values, each cell which is serving the user equipment being associated with a set of measurement parameters or a threshold value.

78. The base station of any of example embodiments 75-77, wherein the base station is a booster base station and sends instructions with respect to a cell associated with the booster base station.

According to some of the example embodiments, the booster base station may also send such instructions to the anchor base station which forwards the instructions to the user equipment on behalf of the booster.

79. The base station of any of example embodiments 63-78, wherein the base station is an anchor base station and the notification is sent from an anchor base station and the handover procedure is solely or also with respect to a booster base station, wherein the notification is an *RRCCOnnectionReconfiguration* message comprising an indication the notification is solely or also for a booster base station.

It should be appreciated that the above may occur when a user equipment is connected to more than one cell or link.

According to some of the example embodiments, this may be indicated with the use of an information element or a PCI of the booster and all the bearers to be setup/modified/released in the booster.

According to some of the example embodiments, this may comprise communicating information about the bearers to be setup/modified/released in both the anchor and booster. This may be indicated by providing for each bearer the PCI of the cell to which the bearer belongs to.

80. The base station of any of example embodiments 63-79, wherein the handover procedure is a subsequent selective handover procedure, where the user equipment has a pre-existing link established with a cell identified in the notification.

PROCEDURES FOR SELECTIVE HANDOVERS AND BEARER MANAGEMENT TO SUPPORT UE MULTIPLE CONNECTIVITY

1 Technical area/Keywords

Heterogeneous networks, Het Net, Pico, Soft cell, Handover, Handoff, LTE, Rel 12

2 Overview

Recent evolvement of telecommunication systems have led to the introduction of Heterogeneous Networks, where the traditional pre-planned macro base stations (known as the *macro layer*) are complemented with several low-powered base stations that may be deployed in a relatively unplanned manner. The 3rd Generation Partnership Project (3GPP) has incorporated the concept of Heterogeneous Networks as one of the core items of study in the latest enhancements of LTE, such as LTE release 11. and several low-powered base stations for realizing heterogeneous networks such as *pico* base stations, *femto* base stations (also known as home base stations or HeNBs), relays, and RRHs (remote radio heads) have been defined.

The initial discussion for LTE release 12 has already started and one of the proposed items for study is the possibility of serving a User Equipment (UE) from more than one eNB simultaneously. The current legacy handover mechanisms of LTE have to be updated in order to support this enhanced solution.

According to some of the example embodiments, the problem of what procedures to use to enable handover of selected bearers from one cell to another while maintaining UE connection to both cells is addressed.

3 Description

3.1 Technical Background / Existing Technology

3.1.1 Overall E-UTRAN architecture

The Evolved UMTS Terrestrial Radio Access Network (E-UTRAN) consists of base stations called enhanced NodeBs (eNBs or eNodeBs), providing the E-UTRA user plane and control plane protocol terminations towards the UE. The eNBs are interconnected with each other by means of the X2 interface. The eNBs are also connected by means of the S1 interface to the EPC (Evolved Packet Core), more specifically to the MME (Mobility Management Entity) by means of the S1-MME interface and to the Serving Gateway (S-GW) by means of the S1-U interface. The S1 interface supports many-to-many relation between MMEs / S-GWs and eNBs. The E-UTRAN architecture is illustrated in Figure 1 below.

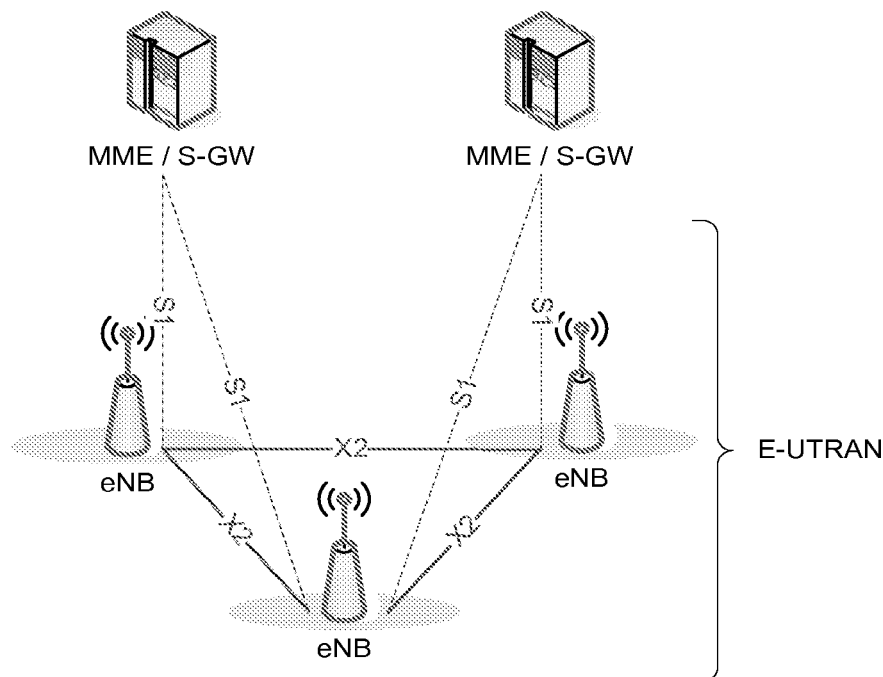


Figure 1: Overall E-UTRAN Architecture

The eNB hosts functionalities such as Radio Resource Management (RRM), radio bearer control, admission control, header compression of user plane data towards serving gateway, routing of user plane data towards the serving gateway. The MME is the control node that processes the signalling between the UE and the CN. The main functions of the MME are related to connection management and bearer management, which are handled via Non Access Stratum (NAS) protocols. The S-GW is the anchor point for UE mobility, and also comprises other functionalities such as temporary DL data buffering while the UE is being paged, packet routing and forwarding the right eNB, gathering of information for charging and lawful interception. The PDN Gateway (P-GW) is the node responsible for UE IP address allocation, as well as Quality of Service (QoS) enforcement (this is explained further in later sections). Figure 2 gives a summary of the functionalities of the different nodes, and the reader is referred to 3GPP TS 36.300 and the references therein for the details of the functionalities of the different nodes. In Figure 2, the yellow boxes depict the logical nodes, white boxes depict the functional entities of the control plane and blue boxes depict the radio protocol layers.

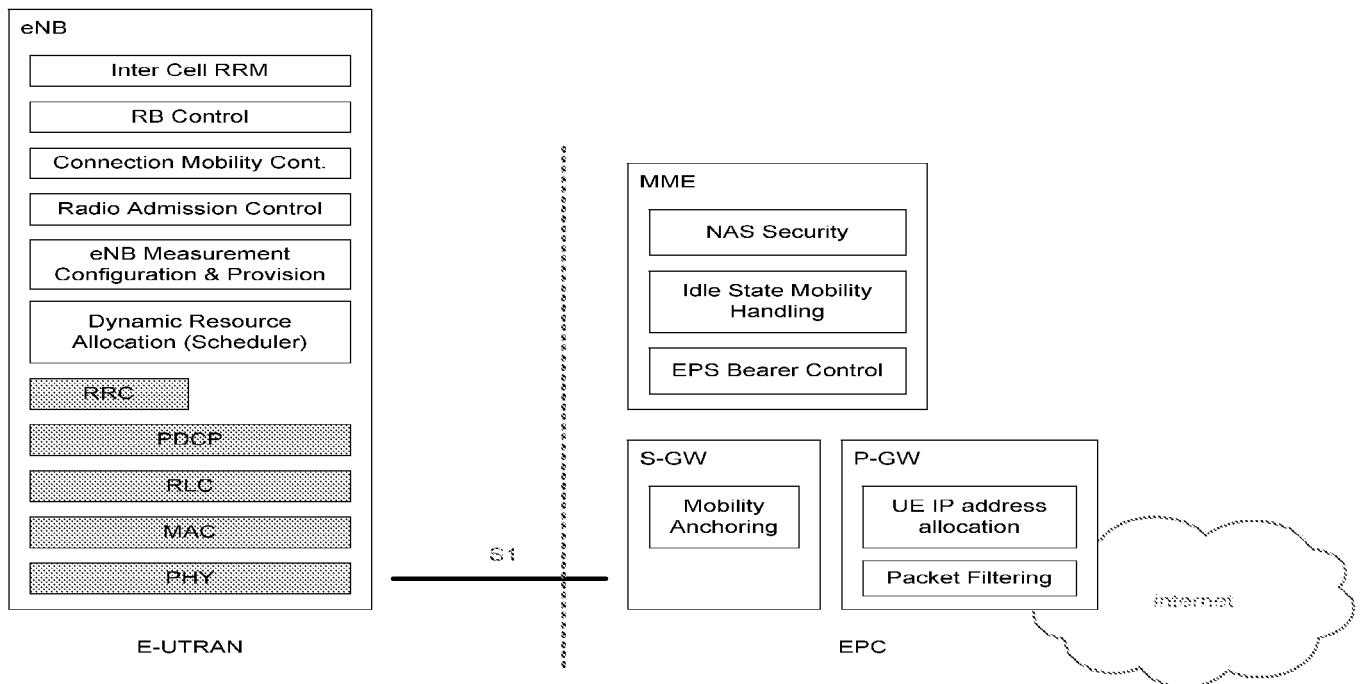


Figure 2: Functional Split between E-UTRAN and EPC

3.1.2 Radio Protocol architecture

The radio protocol architecture of E-UTRAN is divided into the user plane and the control plane.

3.1.2.1 User plane

Figure 3 shows the protocol stack for the user-plane. The user plane protocol stack is comprised of the Packet Data Convergence Protocol (PDCP), Radio Link Control (RLC), and Medium Access Control (MAC), which are terminated at the eNB. The PDCP manages IP packets in the user plane and it performs functionalities such as header compression, security, and re-ordering and retransmission during handover. The RLC layer is mainly responsible for segmentation (and corresponding assembly) of PDCP packets, in order that they fit the size that is actually to be transmitted over the air interface. RLC can operate either in unacknowledged mode or acknowledged mode, where the latter supports retransmissions. The MAC layer performs multiplexing of data from different radio bearers, and it is the one that informs the RLC about the size of the packets to provide, which is decided based on the required QoS of each radio bearer and the current capacity available to the UE.

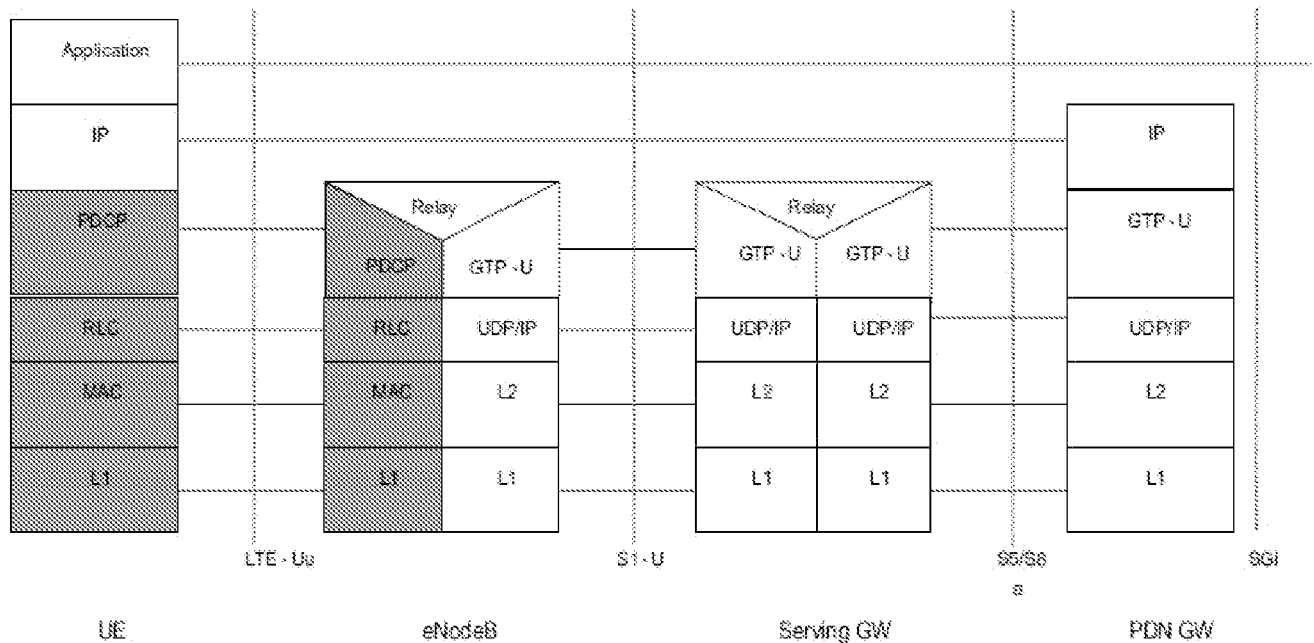


Figure 3: User plane protocol stack

3.1.2.2 Control plane

Figure 4 shows the control plane protocol stack. The layers below the Radio Resource Control (RRC) layer perform the same functionality as in the user plane except that there is no header compression in the control plane. The main functions of the RRC are the broadcasting of system information, RRC connection control (establishment, modification, and release of RRC connection, establishment of signalling radio bearers (SRB) and data radio bearers (DRBs), handover, configuration of lower protocol layers, radio link failure recovery, etc...), and measurement configuration and reporting. The details of the RRC protocol functionalities and procedures can be found in 3GPP TS 36.331.

A UE is uniquely identified over the S1 interface within an eNB with the eNB UE S1AP ID. When an MME receives an eNB UE S1AP ID it stores it for the duration of the UE-associated logical S1-connection for this UE. Once known to an MME this IE is comprised in all UE associated S1-AP signalling. The eNB UE S1AP ID is unique within the eNB, and UEs are assigned new S1AP ID after a handover by the target eNB.

From the MME side, a UE is uniquely identified using the MME UE S1AP ID. When an eNB receives MME UE S1AP ID it stores it for the duration of the UE-associated logical S1 connection for this UE. Once known to an eNB this IE is comprised in all UE associated S1-AP signalling. The MME UE S1AP ID is unique within the MME, and it is changed if the UE's MME changes (for example, handover between two eNBs connected to different MMEs).

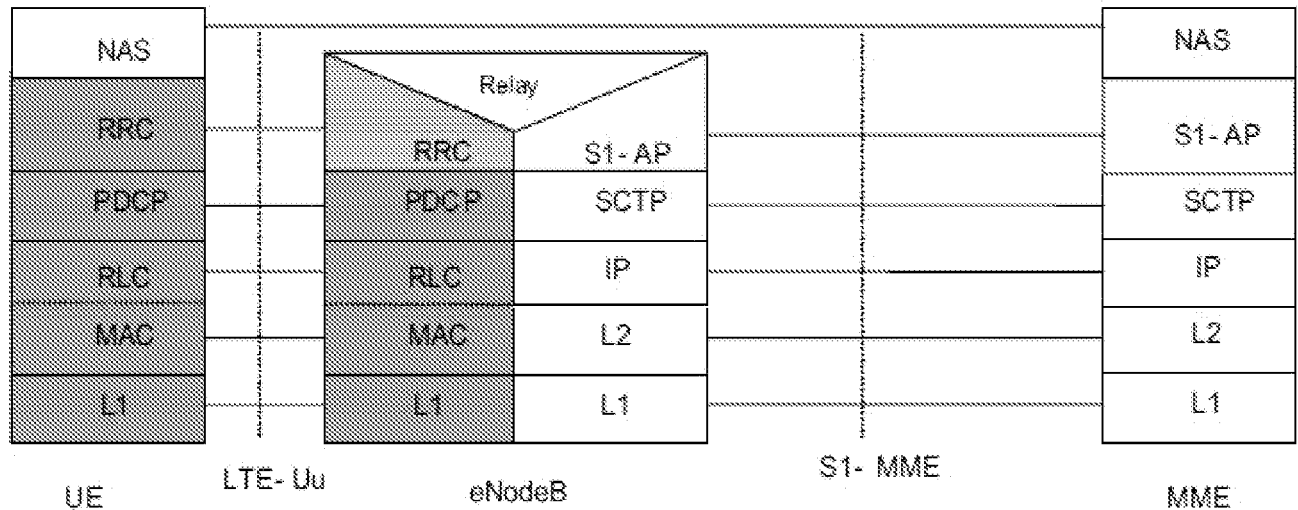


Figure 4: Control plane protocol stack

3.1.2.3 Flow of user plane and control plane data

The flow of user plane and control plane data is illustrated in Figure 5. There is only one MAC entity per UE (unless the UE supports multiple carriers in the case of carrier aggregation) and under this MAC entity, several Hybrid ARQ (HARQ) processes might be running simultaneously for rapid retransmissions. There is a separate RLC entity for each radio bearer and if the radio bearer is configured to use PDCP, there is also one separate PDCP entity for that bearer. A bearer is configured to use PDCP only if it is dedicated to a UE (i.e. multicast and broadcast data do not utilize PDCP both in the control and user plane and the PDCP is used only for dedicated control message in the control plane and for dedicated UL/DL data in the user plane).

At the transmitting side each layer receives a Service Data Unit (SDU) from a higher layer, and sends a Protocol Data Unit (PDU) to the lower layer. For example, PDCP PDUs are sent towards the RLC, and they are RLC SDUs from RLC point of view, which in turn sends RLC PDUs towards the MAC, which are MAC SDUs from the MAC point of view. At the receiving end, the process is reversed, i.e. each layer passing SDUs to the layer above it, where they are perceived as PDUs.

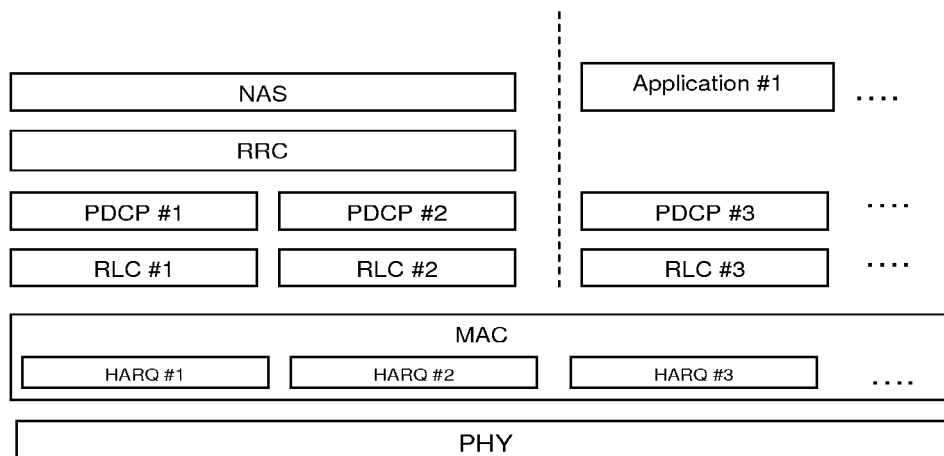


Figure 5: User plane and control plane data flow.

3.1.3 QoS

A UE can have multiple applications running at the same time, each having different QoS requirements (for example, VoIP, browsing, file download ...). In order to support these different requirements, different bearers are set up, each being associated with a QoS. An EPS bearer/E-RAB (Radio Access Bearer) is the level of granularity for bearer level QoS control in the EPC/E-UTRAN. That is, Service Data Flows (SDF) mapped to the same EPS bearer receive the same bearer level packet forwarding treatment (e.g. scheduling policy, queue management policy, rate shaping policy, RLC configuration, etc.) .

One EPS bearer/E-RAB is established when the UE connects to a PDN, and that remains established throughout the lifetime of the PDN connection to provide the UE with always-on IP connectivity to that PDN. That bearer is referred to as the *default* bearer. Any additional EPS bearer/E-RAB that is established to the same PDN is referred to as a *dedicated* bearer. The initial bearer level QoS parameter values of the default bearer are assigned by the network, based on subscription data. The decision to establish or modify a dedicated bearer can only be taken by the EPC, and the bearer level QoS parameter values are always assigned by the EPC.

An EPS bearer/E-RAB is referred to as a GBR bearer if dedicated network resources related to a Guaranteed Bit Rate (GBR) value that is associated with the EPS bearer/E-RAB are permanently allocated (e.g. by an admission control function in the eNB) at bearer establishment/modification. Otherwise, an EPS bearer/E-RAB is referred to as a Non-GBR bearer. A dedicated bearer can either be a GBR or a Non-GBR bearer while a default bearer shall be a Non-GBR bearer.

The EPS bearer service architecture is shown in Figure 6. The packets of an EPS bearer are transported over a radio bearer between the UE and eNB. An S1 bearer transports the packets of an EPS bearer between the eNB and S-GW. An E-RAB is actually a concatenation of these two bearers (i.e. radio bearer and S1 bearer), and the two bearers are mapped on a one to one fashion. An S5/S8 bearer transports the packets of the EPS bearer between the S-GW and P-GW, and completes the EPS bearer. Here also there is a one to one mapping between the E-RAB and S5/S8 bearer.

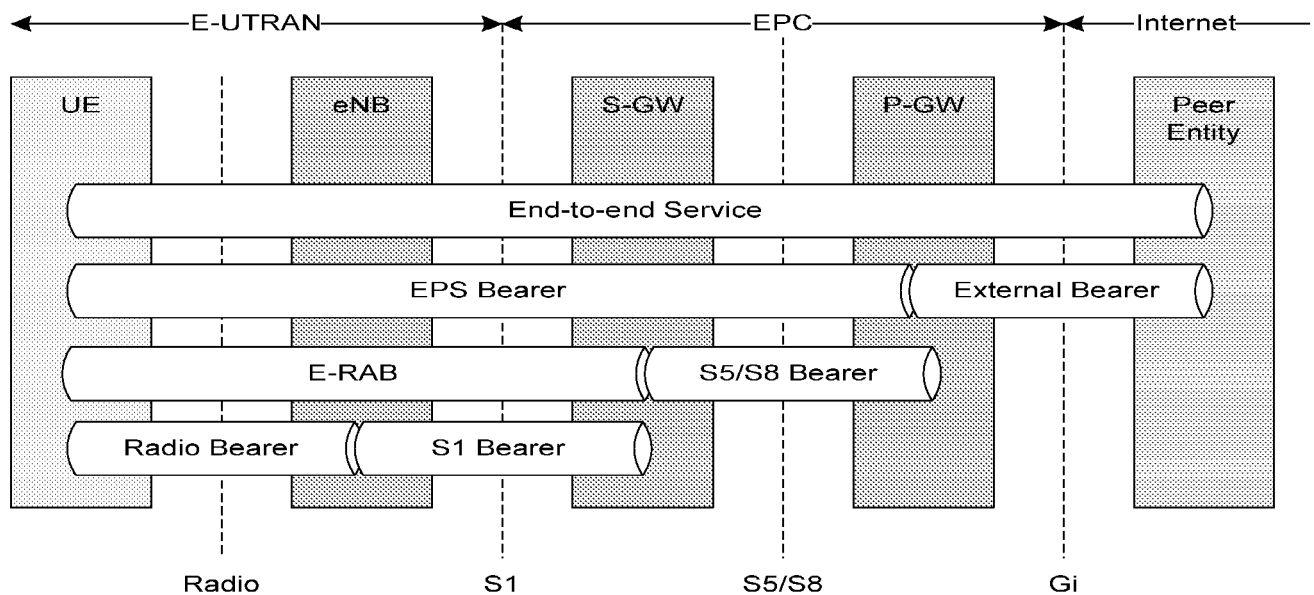


Figure 6: EPS Bearer Service Architecture

The bearer level (i.e. per bearer or per bearer aggregate) QoS parameters are QCI, ARP, GBR, and AMBR. Each EPS bearer/E-RAB (GBR and Non-GBR) is associated with the following bearer level QoS parameters:

- **QoS Class Identifier (QCI):** scalar that is used as a reference to access node-specific parameters that control bearer level packet forwarding treatment (e.g. scheduling weights, admission thresholds, queue management thresholds, link layer protocol configuration, etc.), and that have been pre-configured by the operator owning the eNodeB. Nine QCI values are standardized the detailed requirements of these classes can be found in 3GPP TS 23.203.
- **Allocation and Retention Priority (ARP):** the primary purpose of ARP is to decide whether a bearer establishment / modification request can be accepted or needs to be rejected in case of resource limitations. In addition, the ARP can be used by the eNodeB to decide which bearer(s) to drop during exceptional resource limitations (e.g. at handover).

Each GBR bearer is additionally associated with the following bearer level QoS parameters:

- **Guaranteed Bit Rate (GBR):** the bit rate that can be expected to be provided by a GBR bearer
- **Maximum Bit Rate (MBR):** the maximum bit rate that can be expected to be provided by a GBR bearer. MBR can be greater or equal to the GBR.

Each APN access, by a UE, is associated with a per-APN Aggregate Maximum Bit Rate (APN-AMBR). The APN-AMBR sets the limit on the aggregate bit rate that can be expected to be provided across all Non-GBR bearers and across all PDN connections of the same APN.

Each UE in state EMM-REGISTERED is associated with the bearer aggregate level QoS parameter known as per UE Aggregate Maximum Bit Rate (UE-AMBR). The UE-AMBR

limits the aggregate bit rate that can be expected to be provided across all Non-GBR bearers of a UE.

3.1.4 Heterogeneous Networks and Soft/Shared Cells

The use of a so called *heterogeneous deployment* or *heterogeneous network*, as illustrated in Figure 7, consisting of network transmission nodes with different transmit power operating and with overlapping coverage areas, is considered to be an interesting future deployment strategy for cellular networks. In such a deployment, the low-power nodes ("pico nodes") are typically assumed to offer high data rates (Mbit/s), as well as provide high capacity (users/m² or Mbit/s/m²), in the local areas where this is needed/desired, while the high-power nodes ("macro nodes") are assumed to provide full-area coverage. In practice, the macro nodes may correspond to currently deployed macro cells while the pico nodes are later deployed nodes, extending the capacity and/or achievable data rates within the macro-cell coverage area where needed.

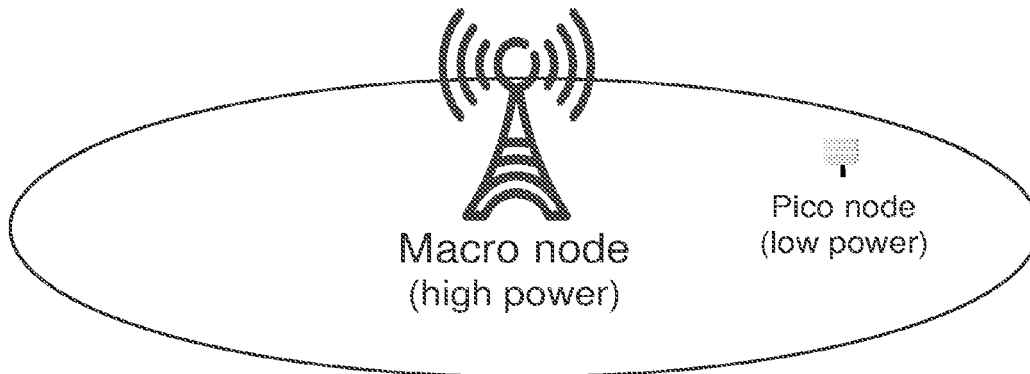


Figure 7: Heterogeneous deployment with a higher-power macro node and a lower-power pico node. In a typical case, there may be multiple pico nodes within the coverage area of a macro node.

A pico node of a heterogeneous deployment may correspond to a cell of its own (a "pico cell"), see Figure 8. This means that, in addition to downlink and uplink data transmission/reception, the pico node also transmits the full set of common signals/channels associated with a cell. In the LTE context this comprises:

- The *Primary and Secondary Synchronization Signals* (PSS and SSS) corresponding to the *Physical Cell Identity* of the pico cell.
- The *Cell-specific reference signals* (CRS), also corresponding to the *Physical Cell Identity* of the cell. The CRS can e.g. be used for downlink channel estimation to enable coherent demodulation of downlink transmissions.
- The *Broadcast channel* (BCH), with corresponding pico-cell system information¹

As the pico node transmits the common signals/channels, the corresponding pico cell can be detected and selected (connected to) by a terminal (UE, user equipment).

¹ Additional system information is transmitted on the PDSCH physical channel

If the pico node corresponds to a cell of its own, also so-called *L1/L2 control signalling* on the PDCCH (as well as PCFICH and PHICH) are transmitted from the pico node to connected terminals, in addition to downlink data transmission on the PDSCH. The L1/L2 control signalling e.g. provides downlink and uplink scheduling information and Hybrid-ARQ-related information to terminals within the cell. This is shown in Figure 8.

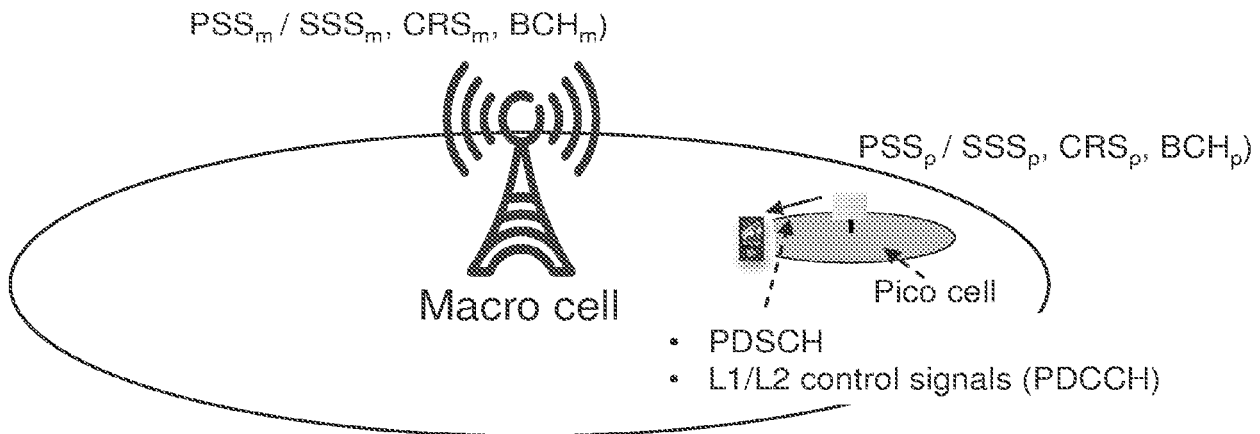


Figure 8: Heterogeneous deployment where the pico node corresponds to a cell of its own (a "pico cell"). The indices "p" and "m" indicate common signals/channels for the pico and macro cell respectively.

Alternatively, a pico node within a heterogeneous deployment may not correspond to a cell of its own but may just provide a data-rate and capacity "extension" of the overlaid macro cell, see e.g. P32215. This is sometimes known as "shared cell" or "soft cell". In this case at least the CRS, PBCH, PSS and SSS are transmitted from the macro node. The PDSCH can be transmitted from the pico node. To allow for demodulation and detection of the PDSCH, despite the fact that no CRS is transmitted from the pico node, DM-RS should be transmitted from the pico node together with the PDSCH. The UE-specific reference signals can then be used by the terminal for PDSCH demodulation/detection. This is shown in Figure 9.

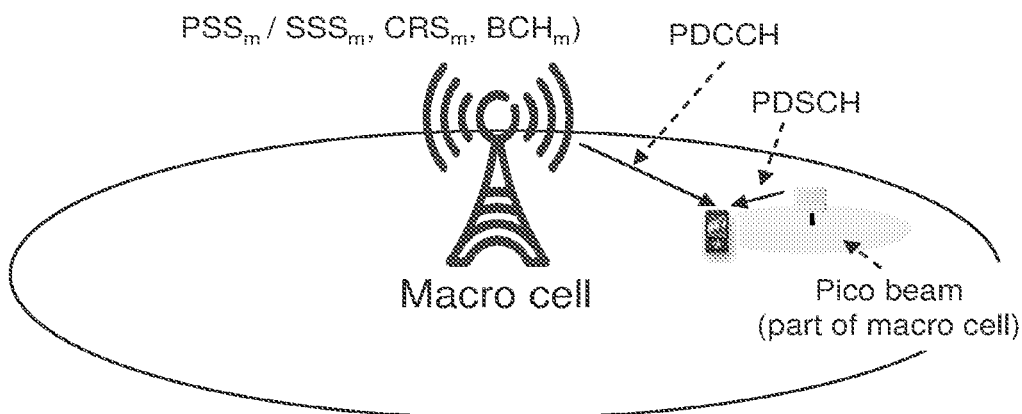


Figure 9: Heterogeneous deployment where the pico node does not correspond to a cell of its own

Transmitting data from a pico node not transmitting CRS as described above requires DM-RS support in the terminal (“non-legacy terminal”). In LTE, DM-RS-based PDSCH reception is supported in Rel-10 and for FDD while for the L1/L2 control signalling, DM-RS-based reception is planned for Rel-11. For terminals not supporting DM-RS-based reception (“legacy terminals”) one possibility in a shared cell setting is to exploit SFN²-type of transmission. In essence *identical* copies of the signals and channels necessary for a legacy terminal are transmitted *simultaneously* from the macro and pico nodes. From a terminal perspective this will look as a single transmission. Such an operation, which is illustrated in Figure 10, will only provide an SINR gain, which can be translated into a higher data rate but not a capacity improvement, as transmission resources cannot be reused across sites within the same cell.

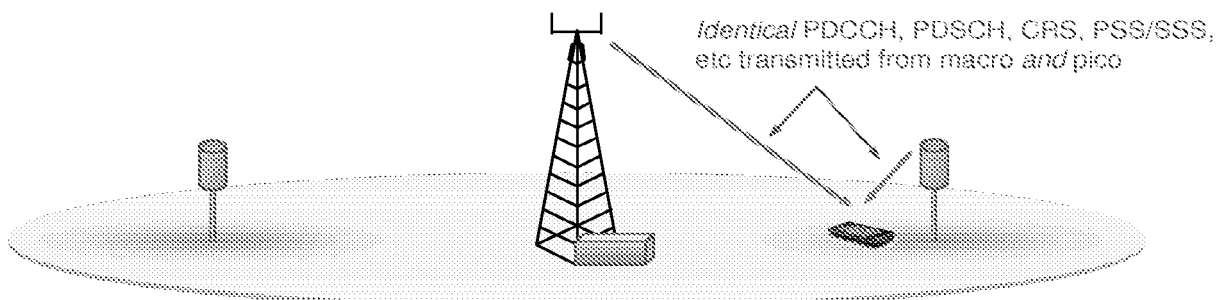


Figure 10: SFN operation with *identical* transmission from macro and pico to a terminal.

If we can assume that the macros are able to provide coverage and the picos are there only for capacity enhancements (i.e. no coverage holes), another alternative architecture is where the UE maintains the macro connectivity all the time (called the “anchor” link), and adds the pico connectivity when it is in the coverage area of the pico (called the “booster” link). When both connections are active, the anchor link can be used either for control signalling while the booster link is used for data. However, it will still be possible to send data also via the anchor link. This is illustrated in Figure 11. Note that in this case, as in the previous cases, the system information is shown to be sent only from the macro, but it is still possible to send it also from the picos.

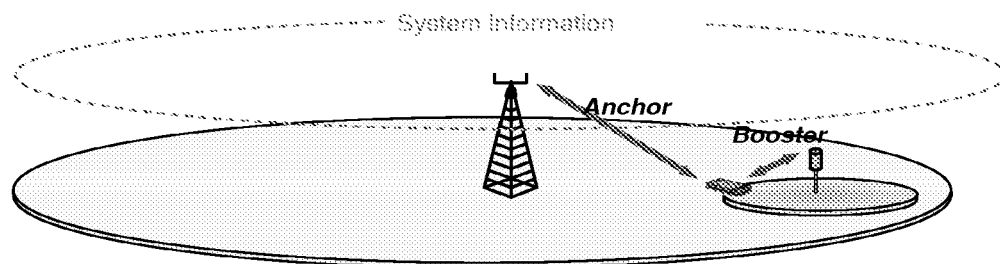


Figure 11: Soft cell operation with the UE having multiple connections with both the anchor and booster.

² Single Frequency Network

3.1.4.1 Protocol architecture for Soft Cells

In order to support multiple connectivity, several architectural options are possible both for the control and user plane. For the user plane, we can have a centralized approach where the PDCP (or even the RLC) is terminated at the anchor only and the booster terminates at the RLC (or even the MAC) level. A decentralized approach will be to have the booster to terminate at the PDCP level. Similar approach can be taken in the control plane (i.e. distributed or centralized PDCP/RLC,) but on top of that we have the additional dimension of centralizing or distributing the RRC. Figure 12 shows example control and user plane architectures, where the user plane is employing distributed PDCP, while the control plane is centralized at the PDCP level at the anchor. Note that in the figure, user plane aggregation (i.e. the possibility to split the packets belonging to one application data flow over the anchor and booster links) can be realized by using a higher layer aggregation protocol like multi-path TCP (MPTCP). According to some of the example embodiments, the control plane is assumed to be like the one shown in the figure.

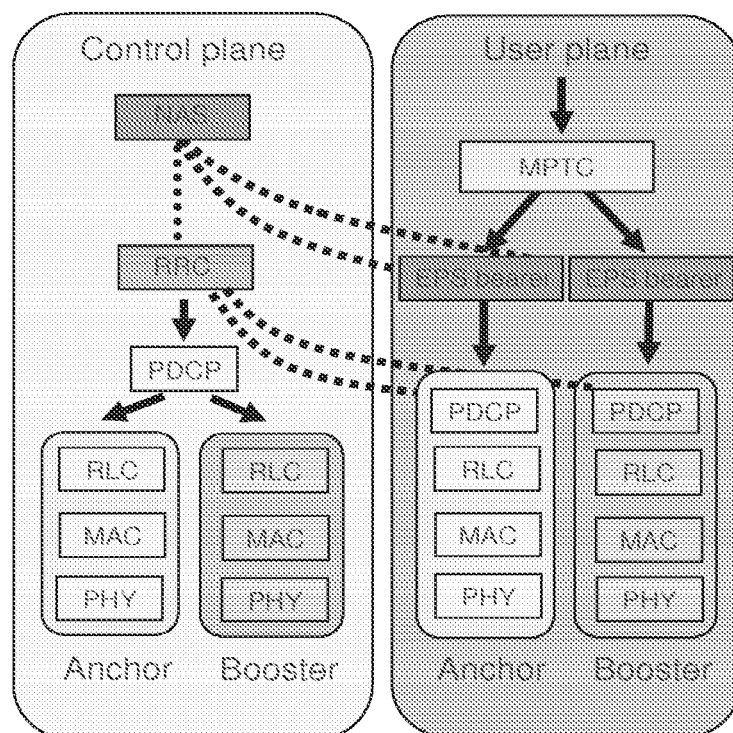


Figure 12: Protocol architecture for multiple connectivity.

3.1.5 UE measurements

UEs can be configured to report measurements, mainly for the sake of supporting mobility. As specified in 3GPP TS 36.331, the E-UTRAN provides the measurement configuration applicable for a UE in RRC_CONNECTED by means of dedicated signalling, i.e. using the *RRCConnectionReconfiguration* message. The following measurement configurations can be signalled to the UE:

1. **Measurement objects:** These define on what the UE should perform the measurements – such as a carrier frequency. The measurement object may also

comprise a list of cells to be considered (white-list or black-list) as well as associated parameters, e.g. frequency- or cell-specific offsets.

2. **Reporting configurations:** These consist of the periodic or event-triggered criteria which cause the UE to send a measurement report, as well as the details of what information the UE is expected to report (e.g. the quantities, such as Received Signal Code Power (RSCP) for UMTS or Reference Signal Received Power (RSRP) for LTE, and the number of cells).
3. **Measurement identities:** These identify a measurement and define the applicable measurement object and reporting configuration. Each measurement identity links one measurement object with one reporting configuration. By configuring multiple measurement identities it is possible to link more than one measurement object to the same reporting configuration, as well as to link more than one reporting configuration to the same measurement object. The measurement identity is used as a reference number in the measurement report.
4. **Quantity configurations:** The quantity configuration defines the filtering to be used on each measurement. One quantity configuration is configured per RAT type, and one filter can be configured per measurement quantity.
5. **Measurement gaps:** Measurement gaps define time periods when no uplink or downlink transmissions will be scheduled, so that the UE may perform the measurements (e.g. inter-frequency measurements where the UE has only one Tx/Rx unit and supports only one frequency at a time). The measurement gaps are common for all gap-assisted measurements

The E-UTRAN configures only a single measurement object for a given frequency, but more than one measurement identity may use the same measurement object. The identifiers used for the measurement object and reporting configuration are unique across all measurement types. It is possible to configure the quantity which triggers the report (RSCP or RSRP) for each reporting configuration.

In LTE, some examples of measurements metric used are the Reference Signal Received Power (RSRP) and Reference Signal Received Quality (RSRQ). RSRP is a cell specific measure of signal strength and it is mainly used for ranking different cells for handover and cell reselection purposes, and it is calculated as the linear average of the power of the Resource Elements (REs) which carry cell-specific Reference Signals (RSs). The RSRQ, on the other hand, also takes the interference into consideration by taking the total received wideband power into account as well.

One of the measurement configuration parameters that UEs receive from their serving eNBs is the *S-measure*, which tells the UE when to start measuring neighbouring cells. If the measured RSRP of the serving cell falls below the S-measure, indicating the signal of the serving cell is not that strong anymore, the UE starts measuring the signal strength of RSs from the neighbouring cells. The S-measure is an optional parameter and different S-measure values can be specified for initiating intra-frequency, inter-frequency and inter-RAT measurements.

Once the UE is enabled for measuring, it can report any of the following:

- The serving cell
- Listed cells (i.e. cells indicated as part of the measurement object);
- Detected cells on a listed frequency (i.e. cells which are not listed cells but are detected by the UE).

There are several measurement configuration parameters that specify the triggering of measurement reports from the UE. The following event-triggered criteria are specified for intra-RAT measurement reporting in LTE:

- **Event A1:** Primary serving cell (PCell) becomes better than absolute threshold.
- **Event A2:** PCell becomes worse than absolute threshold.
- **Event A3:** Neighbour cell becomes better than an offset relative to the PCell.
- **Event A4:** Neighbour cell becomes better than absolute threshold.
- **Event A5:** PCell becomes worse than one absolute threshold and neighbour cell becomes better than another absolute threshold.
- **Event A6:** Neighbour cell becomes better than an offset relative to a secondary cell (SCell)

For inter-RAT mobility, the following event-triggered reporting criteria are specified:

- **Event B1:** Neighbour cell becomes better than absolute threshold.
- **Event B2:** Serving cell becomes worse than one absolute threshold and neighbour cell becomes better than another absolute threshold.

An example measurement report triggering event related to handover is A3, and its usage is illustrated in Figure 13. The triggering conditions for event A3 can be formulated as:

$$N > S + HOM \quad (1)$$

where N and S are the signal strengths of the neighbour and serving cells, respectively, and HOM is the handover margin. HOM is the difference between the radio quality of the serving cell and the radio quality needed before attempting a handover. The radio quality is measured either using RSRP or RSRQ (see 36.133 for further explanation).

The UE triggers the intra-frequency handover procedure by sending event A3 report to the eNB. This event occurs when the UE measures that the target cell is better than the serving cell with a margin “HOM”. The UE is configured over RRC when entering a cell and the HOM is calculated from the following configurable parameters:

$$HOM = Of_s + Ocs + Off - Of_n - Ocn + Hys$$

Where:

Of_s is the frequency specific offset of the serving cell

Ocs is the cell specific offset (CIO) of the serving cell

Off is the a3-Offset

Of_n is the frequency specific offset of the neighbor cell

Ocn is the CIO of the neighbor cell

Hys is the hysteresis

If the condition in (1) is satisfied and it remains valid for a certain duration known as Time To Trigger (TTT), the UE sends a measurement report to the serving eNB (in Figure 3, event A3 is satisfied at point A and measurement report is sent at point B in time). When the serving eNB gets the measurement report, it can initiate a handover towards the neighbour.

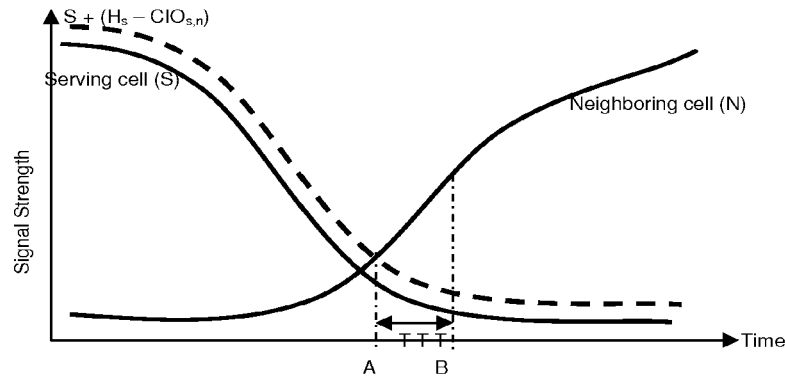


Figure 13: Handover triggering in LTE

In addition to event-triggered reporting, the UE may be configured to perform periodic measurement reporting. In this case, the same parameters may be configured as for event-triggered reporting, except that the UE starts reporting immediately rather than only after the occurrence of an event.

3.1.6 Handover

Handover is one of the important aspects of any mobile communication system, where the system tries to assure service continuity of the User Equipment (UE) by transferring the connection from one cell to another depending on several factors such as signal strength, load conditions, service requirements, etc. The provision of efficient/effective handovers (minimum number of unnecessary handovers, minimum number of handover failures, minimum handover delay, etc.), would affect not only the Quality of Service (QoS) of the end user but also the overall mobile network capacity and performance.

In LTE, UE-assisted, network controlled handover is utilized (3GPP TS 36.300). The handover is based on UE reports, and the UE is moved, if required and possible, to the most appropriate cell that will assure service continuity and quality.

Handover is performed via the X2 connection, whenever available, and if not, using S1 (i.e. involving the Core Network (CN)). The X2 Handover process is shown in Figure 14. The handover procedure can be sub divided into three stages of *preparation (initiation)*, *execution* and *completion*.

During the preparation stage, based on the measurement results the source eNB is getting from the UE, the source eNB decides whether to handover the connection to another eNB or not. If the decision is to handover, the source eNB sends a HANDOVER REQUEST message to the target eNB. The source eNB must indicate the cause of the HO in this message, which can be, e.g.,

- Handover Desirable for Radio Reasons,
- Resource Optimisation Handover,
- Reduce Load in Serving Cell

Thus the target eNB knows that the HO is due to resource optimization or to reduce the load in the serving cell. If the target eNB is able to admit the UE, a message is sent to the UE to initiate the handover, and we enter the handover execution state. DL data arriving at the source eNB for the UE are then forwarded to the new target eNB.

The handover completion stage is entered once the target eNB and the UE are synchronized and a handover confirm message (step 11 of Figure 6) is received by the target eNB. After a proper setup of the connection with the target eNB is performed (which comprise the switching of the DL path in the serving gateway), the old connection is released and any remaining data in the source eNB that is destined for the UE is forwarded to the target eNB. Then normal packet flow can ensue through the target eNB.

3.2 Overview of the example embodiments

LTE currently supports only one to one connections between UEs and eNBs. As such, when a handover is initiated, the target is asked to admit all the bearers of the UE. If for some reason, such as overload situation, that some of the bearers can't be admitted at the target, the source can either cancel the handover (and possibly try another candidate target) or accept it and handover the UE to the target, which will result in the dropping of the non-admitted bearers. This can have severe consequences on the overall experience of the user.

Further, the handover procedures specified in 3GPP are aimed at keeping the UE connected to only one cell. Namely, when a handover procedure is completed, the UE moves all or part of its data and signalling bearers to the target, leaving no further communication with the source.

With the advent of soft cells, new handover mechanisms (triggering, preparation, execution) that can take advantage of the possibility to connect a UE to multiple eNBs at the same time are required. In fact, current specifications do not allow to setup bearers in parallel and in multiple eNBs for the same UE. This would allow an optimal distribution of bearers depending on their QoS and UL/DL requirements. According to some of the example embodiments, the procedural aspects of mobility, bearer establishment and maintenance with soft cells is addressed.

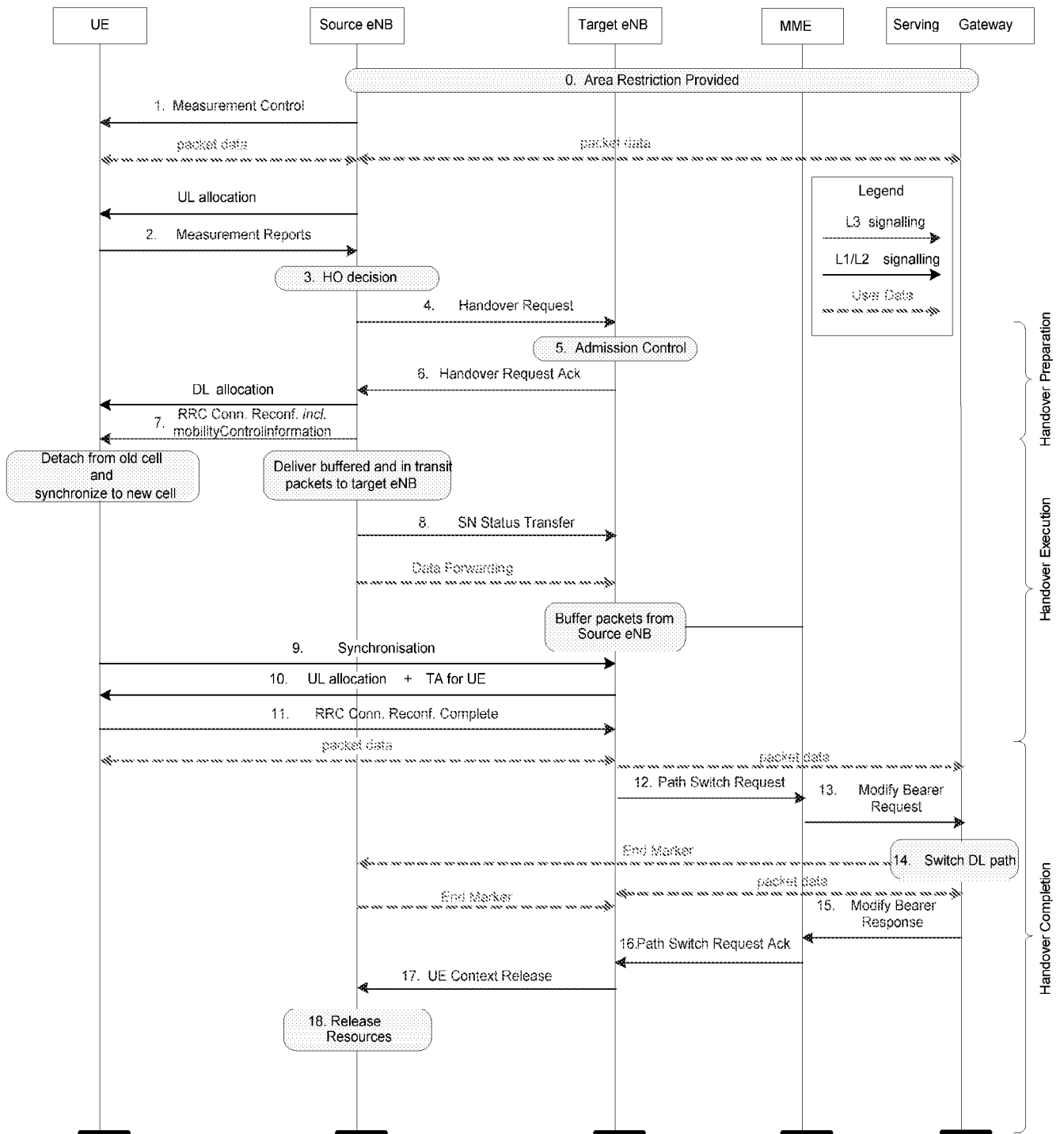


Figure 14: X2 Handover in LTE

4 Brief summary of the example embodiments

According to some of the example embodiments, the procedures used to setup, modify and tear down bearers between anchor and booster nodes are described. Also, procedures aimed at enabling selective handover decisions are defined.

In general, the terms anchor node and booster node, or anchor cell and booster cell are used to identify a serving cell (anchor cell) hosted by a serving node (anchor node) and a neighbour cell (booster cell) hosted by a neighbour node (booster node), where bearers for the same UE are moved, setup, modified or removed in both cells at the same time and where the main control plane connection for the served UE is either kept at the anchor node or it is relayed by the anchor node.

According to some of the example embodiments, two main alternatives may be highlighted:

- 1) to exploit the presence of the existing X2 interface between anchor and booster node and to enhance existing X2 procedures or introduce new procedures
- 2) to introduce a new interface, for example called X3, between the anchor node and the booster node, mainly used, but not limited to, procedures associated with mobility and bearer management between anchor nodes and booster nodes.

According to some of the example embodiments, a focus on enhancing the handover procedures, used either on X2 interface or used on a new X3 interface, to introduce new information allowing the target node to understand that the procedure in place is for a selective handover (as described in P38076 – selective handover IvD) and to allow appropriate handling of bearers mobility in such scenario is provided.

According to some of the example embodiments, a focus on defining new procedures for the management and tearing down of bearers in booster cell is also provided. This is achieved by reusing procedures similar to the bearer management procedures available over the S1 interface, as defined in TS36.413.

According to some of the example embodiments, procedures to notify handover execution completion and to notify via handover preparation procedures whether the handover is selective or not are provided.

According to some of the example embodiments, procedures to exchange information about whether a node or a cell within a node supports selective handover and it provides solutions to allow a node to build a database of neighbour nodes or cells information concerning whether they support selective handovers are introduced.

According to some of the example embodiments, procedures to forward measurement reports from the anchor node to the booster node, with the objective of allowing the booster node to take a decision on whether the UE shall be handed over to a different booster are addressed.

As an extension of the handover decision making process at the booster node for mobility of UE bearers served by the booster, procedures are defined to signal specific measurement configurations from booster node to anchor node.

5 Detailed description of the example embodiments

5.1 General overview

According to some of the example embodiments, the procedures described can be either applied to a new interface adopted for communication between anchor node and booster node, for instance called X3, or they can be applied to the existing X2 interface connecting two eNBs.

Figure 15 describes the potential interfaces between eNBs in a EUTRAN architecture where eNBs can either be anchor nodes or booster nodes or both. In Figure 15, neighbouring eNBs could either be connected via an X2 interface enhanced with the procedures described with respect to the example embodiments report or they could be connected via an X2 interface and an X3 interface, where the latter supports the procedures described in the example embodiments report.

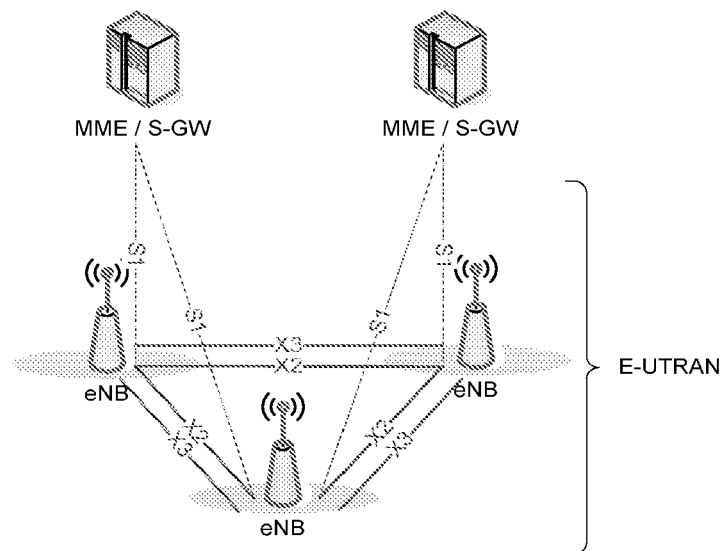


Figure 15: Interfaces options for anchor and booster cell E-UTRAN Architecture

According to some of the example embodiments, the procedures used for selective handovers. Namely, the handover procedures involves the handing over of a subset of UE bearers to a target cell while some other UE bearers are kept active in the source cell, enabling bearer traffic transmission to the same UE from at least two different cells.

As explained in P38076 (Selective HO IvD) and with reference to Figure 12, the protocol architecture assumed for the scenarios considered is based on the assumption of a centralised RRC protocol, where the centralisation node can either be connected or co-located or be the same node as the anchor node. When performing a selective handover and due to the fact that RRC termination is either at the anchor node or through the anchor node, it can be assumed that the RRC Connection Reconfiguration Complete message (message 11 in Figure 14) is not sent from the UE to the target node, but it is sent from the UE to the serving anchor node. This constitutes a change with respect to current specifications and it means that the target booster node is not aware of whether the handover execution was completed by the UE. To overcome this problem a new handover completion procedure is defined. The handover completion procedure may be either constituted by a single message e.g. named the HANDOVER COMPLETED message sent from source eNB to target eNB, or it may be constituted of two messages: the HANDOVER COMPLETED REQUEST message and HANDOVER COMPLETED RESPONSE message. Figure 16 shows an example of the procedure according to the two embodiments outlined, where eNB1 is the anchor node and eNB2 is the booster node.

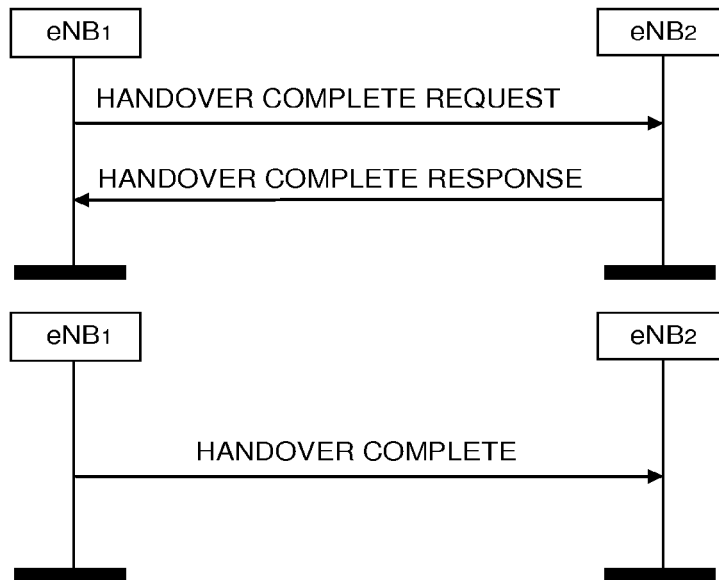


Figure 16: Examples of handover completion procedures

The HANDOVER COMPLETION REQUEST or HANDOVER COMPLETE messages may comprise a *Message Type* IE (as defined in TS36.423) and it may comprise some or all of the following IEs:

- The message may comprise some or all of the IEs present in the RRCConnectionReconfigurationComplete message defined in TS36.331.
- The message may comprise UE specific identifications for the UE handed over
- The message may comprise specific identification for the handover preparation procedure to which the message corresponds to
- The message may comprise an IE specifying whether the handover was completed successfully or whether it failed to complete

The HANDOVER COMPLETION REQUEST or HANDOVER COMPLETE message may serve also an additional purpose, namely they could indicate to the target eNB that a legacy handover for which not all bearers were successfully relocated to target has been converted to a selective handover, where the bearers that failed to be setup in the target node may have been kept active at the source node. To enable such indication another IE can be comprised in these messages, for example named *Selective Handover Indication* IE and defined as in Table 8.

The HANDOVER COMPLETE RESPONSE message comprises a *Message Type* IE (as defined in TS36.423) and it may comprise an IE indicating that the handover was finalised successfully at target eNB.

Additionally, in case of procedures comprising a request and response message, the response from target eNB to source eNB may consist of a HANDOVER COMPLETE FAILURE message. The latter message is used if the handover failed at the target eNB before the handover completion procedures were terminated. The HANDOVER COMPLETE FAILURE message may comprise a *Message Type* IE and a *Cause* IE specifying the cause of failure.

According to some of the example embodiments, procedures for handover preparation are described. For such procedures, the X2 Handover Preparation procedures can be taken into account as baseline messages. This embodiment comprises both the option where the X2 Handover Preparation procedures are enhanced with additional IEs or where procedures similar to X2 Handover Preparation are adopted over a new interface between anchor and booster nodes. A generalized example of these procedure messages is shown in Figure 17. Note that Figure 17 is also present in the handover preparation descriptions in TS36.423, which specify procedures on the X2 interface. However, in this instance, the figure is used in an interface independent way and it could be related to any new interface adopted.

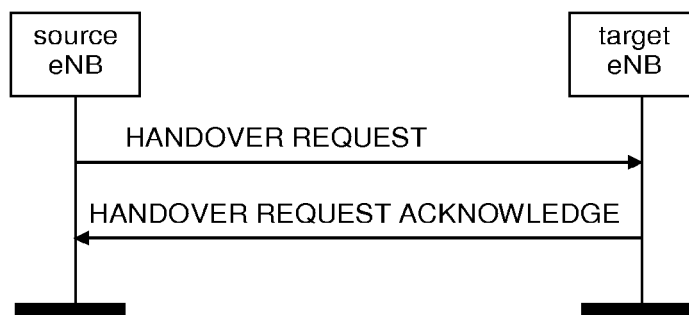


Figure 17: Example of handover preparation procedures.

By taking the X2: HANDOVER REQUEST message as an example, the proposed enhancements consist of letting the target eNB be informed that a given handover is a selective handover rather than a legacy handover (i.e. full handover after which the UE connection is kept in one cell only) by introducing a new optional Information Element (IE) (e.g. "Selective Handover") in the HANDOVER REQUEST message. This IE can take different values depending on the type of selective handover that is being requested. For example, it may have three values, a value of "0" referring to "data radio bearers" (meaning only the data radio bearers listed in the E-RAB list are to be handed over) or value "1" referring to "signalling radio bearers" (meaning only the signalling radio bearers listed in the E-RAB list are to be handed over) or it may have the value "2" referring to "signalling and data radio bearers" (meaning signalling radio bearers as well as the data radio bearers comprised in the E-RAB list are to be handed over). The Selective Handover IE can also be comprised inside the RRC Context IE, which is also comprised in the X2: HANDOVER REQUEST message.

If the procedure is implemented using the X2 interface, the existing IEs in the X2: HANDOVER REQUIRED message can be reused and the additional *Selective Handover* IE can be added.

Table 1 and Table 1a provides an example of IEs comprised in the HANDOVER REQUEST message, where all IEs apart from the *Selective Handover* IE are already present in the X2: HANDOVER REQUEST message.

A second possibility to communicate that the handover is of the selective kind is by including all the bearers of the UE in the E-RABs to be setup list, but adding one optional IE (e.g. "selective hand over") for each bearer indicating whether the concerned bearer is to be handed over or not. This way gives more information to the target than the previous way of including only the bearers to be handed over, as the target will get the whole UE context, and there will be no mismatch between the bearers listed in the E-RABs to be setup list and those in the RRC Context, which might lead to some confusion/errors in some implementations.

A third way to communicate selective handovers is to keep the E-RABs to be setup only to include the bearers to be handed over (as in the first case), but introduce another optional list (e.g. E-RABs to not to be setup) which includes the list of bearers that are to be left at the source. This method effectively provides the same detailed information to the target as in the second case.

By listing all the bearers in the HANDOVER REQUEST message, those to be handed over and those not to be handed over, it is also possible to change the anchor node if needed. The anchor in this case would handover also the signalling radio bearers (SRBs) and it will provide to the new anchor all the UE context information concerning all the bearers the UE has been assigned.

Additionally, the HANDOVER REQUEST may be initiated by a booster node towards an anchor node in order to handover back some bearers that were previously handed over to the booster. As a further option, the booster can indicate in the HANDOVER REQUIRED message an indication that the bearers to be handed over should be handed over to a new booster cell. In the latter case, new information elements need to be added to the HANDOVER REQUEST message in order to specify the identity of the new booster where the bearers need to be handed over.

If shall be pointed out that the HANDOVER REQUEST ACKNOWLEDGE may comprise a list of bearers that were successfully setup, i.e. an *E-RAB Admitted List*, and an *E-RABs Not Admitted List*, i.e. a list of bearers that were not admitted at the booster. Upon reception of the HANDOVER REQUEST ACKNOWLEDGE and of the *E-RABs Not Admitted List* the anchor may decide to maintain the non-admitted bearers active and to keep on serving the UE with these bearers traffic.

Once the first selective handover has been carried out between anchor and booster nodes, there might be the need to hand over more bearers to the booster cell or there might be the need to handover back some bearers from the booster to the anchor. For this purpose the enhanced HANDOVER REQUEST/RESPONSE procedure can be initiated by either the anchor or the booster node. Due to the presence of the *Selective Handover* IE the node receiving subsequent HANDOVER REQUEST messages will understand that they concern a selective handover, i.e. handover of some UE bearers. Therefore reception of such handover messages after the first selective handover has been performed shall not be interpreted as an error. The extra bearers that need to be handed over from anchor to booster or vice versa would be comprised in the *E-RABs To Be Setup List* IE of the HANDOVER REQUEST, while the HANDOVER REQUEST ACKNOWLEDGE may shall comprise an *E-RAB Admitted List* and an *E-RABs Not Admitted List* as specified above.

According to some of the example embodiments, procedures to setup or tear down or modify bearers at the booster cell are defined. As the RRC termination point is either in the anchor node or connected to the anchor node, all these processes shall be triggered by the anchor node.

For this reason E-RAB Setup, E-RAB Modify and E-RAB Release procedures are defined, according to some of the example embodiments, for use on either the X2 interface or on a new interface.

Table 1: Example of enhanced HANDOVER REQUEST message

IE/Group Name	Presence	Range	Semantics description	Criticality	Assigned Criticality
Message Type	M			YES	reject
Old eNB UE X2AP ID	M		Allocated at the source eNB	YES	reject
Cause	M			YES	ignore
Target Cell ID	M			YES	reject
GUMMEI	M			YES	reject
UE Context Information		1		YES	reject
>MME UE S1AP ID	M		MME UE S1AP ID allocated at the MME	–	–
>UE Security Capabilities	M			–	–
>AS Security Information	M			–	–
>UE Aggregate Maximum Bit Rate	M			–	–
>Subscriber Profile ID for RAT/Frequency priority	O			–	–
>E-RABs To Be Setup List		1		–	–
>>E-RABs To Be Setup Item		1 .. <maxnoof Bearers>		EACH	ignore
>>>E-RAB ID	M			–	–
>>>E-RAB Level QoS Parameters	M		comprises necessary QoS parameters	–	–
>>>DL Forwarding	O			–	–
>>>UL GTP Tunnel Endpoint	M		SGW endpoint of the S1 transport bearer. For delivery of UL PDUs.	–	–
>>Selective Handover Bearer Indication	O	Enumerated (true, ...)	Indicates that the bearer is handed over via selective Handover		
>RRC Context	M		Comprises the RRC Handover Preparation Information message as defined in subclause 10.2.2 of TS 36.331 [9].	–	–
>Handover Restriction List	O			–	–
>Location Reporting Information	O		Comprises the necessary parameters for location reporting	–	–
>Management Based MDT Allowed	O			YES	ignore
UE History Information	M		Same definition as in TS 36.413 [4].	YES	ignore
Trace Activation	O			YES	ignore
SRVCC Operation Possible	O			YES	ignore
CSG Membership Status	O			YES	reject
Selective Handover IE	O	Integer (0, 1, 2, ...)	'0' indicates only the data radio bearers listed in the E-RAB list are to be handed over, '1' indicates only the signalling radio bearers listed in the E-RAB list are to be handed over, '2'	YES	reject

			indicates signalling radio bearers and data radio bearers comprised in the E-RAB list are to be handed over		
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Table 2a: Example of enhanced HANDOVER REQUEST message

IE/Group Name	Presence	Range	Semantics description	Criticality	Assigned Criticality
Message Type	M			YES	reject
Old eNB UE X2AP ID	M		Allocated at the source eNB	YES	reject
Cause	M			YES	ignore
Target Cell ID	M			YES	reject
GUMMEI	M			YES	reject
UE Context Information		1		YES	reject
>MME UE S1AP ID	M		MME UE S1AP ID allocated at the MME	–	–
>UE Security Capabilities	M			–	–
>AS Security Information	M			–	–
>UE Aggregate Maximum Bit Rate	M			–	–
>Subscriber Profile ID for RAT/Frequency priority	O			–	–
>E-RABs To Be Setup List		1		–	–
>>E-RABs To Be Setup Item		1 .. <maxnoof Bearers>		EACH	ignore
>>>E-RAB ID	M			–	–
>>>E-RAB Level QoS Parameters	M		comprises necessary QoS parameters	–	–
>>>DL Forwarding	O			–	–
>>>UL GTP Tunnel Endpoint	M		SGW endpoint of the S1 transport bearer. For delivery of UL PDUs.	–	–
>E-RABs Not To Be Switched in Downlink Item IEs	O	1 to <maxnoof E-RABs>	Indicates the list of RABs not to be switched, i.e. not subject to selective handover		
>>E-RABs Not To Be Setup Item		1 .. <maxnoof Bearers>		EACH	ignore
>>>E-RAB ID	M			–	–
>>>E-RAB Level QoS Parameters	M		comprises necessary QoS parameters	–	–
>RRC Context	M		Comprises the RRC Handover Preparation Information message as defined in subclause 10.2.2 of TS 36.331 [9].	–	–
>Handover Restriction List	O			–	–
>Location Reporting Information	O		Comprises the necessary parameters for location reporting	–	–
>Management Based MDT Allowed	O			YES	ignore
UE History Information	M		Same definition as in TS 36.413 [4].	YES	ignore
Trace Activation	O			YES	ignore
SRVCC Operation Possible	O			YES	ignore
CSG Membership Status	O			YES	reject
Selective Handover IE	O	Integer (0, 1, 2, ...)	'0' indicates only the data radio bearers listed in the E-RAB list are to be	YES	reject

			handed over, "1" indicates only the signalling radio bearers listed in the E-RAB list are to be handed over, "2" indicates signalling radio bearers and data radio bearers comprised in the E-RAB list are to be handed over		
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A general diagram of the E-RAB Setup procedure is shown in Figure 18.

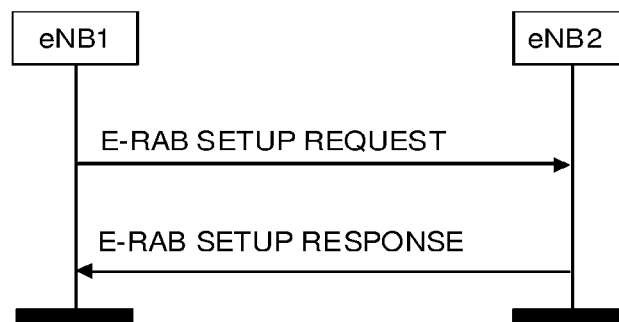


Figure 18: E-RAB Setup procedure

The E-RAB Setup procedure is used after a selective handover has been carried out via handover preparation and handover execution procedures and when additional radio bearers need to be setup at booster cell. This procedure is triggered after a decision has been made in the anchor node about whether one or more bearers need setup directly at the booster cell. Such decision may be based on different factors such as:

- UE radio conditions monitored via reception of measurement reports by the UE
- Load related conditions, i.e. whether the serving anchor cell is in need to offload traffic to a booster cell
- Performance related conditions, i.e. whether it is more opportune for some bearers to be served by the booster cell due to the improved performance the booster node could provide (e.g. in case of bearers with predominant uplink traffic)

In this procedure the anchor node eNB1 sends an E-RAB SETUP REQUEST message to booster node eNB2. The E-RAB SETUP REQUEST comprises a list of bearers that are in need to be setup at the booster node. As a consequence of receiving the E-RAB SETUP REQUEST the booster node shall reply with an E-RAB SETUP RESPONSE message, which comprises a list of successfully setup bearers and a list of bearers that failed to be setup. If the E-RAB SETUP RESPONSE indicates that some of the bearers to be setup failed to be setup, the anchor node may decide to setup such bearers at the anchor cell.

Table 2 shows examples of IEs that could be comprised in the E-RAB Setup Request message either over the X2 interface or over a new interface. In this list the *Transport Layer Address* IE represents the IP address of the node where uplink traffic will need to be sent by the booster eNB. Equivalently, the *GTP-TEID* IE represents the GTP tunnel endpoint ID of the node terminating the GTP tunnel established with the booster node. The remaining IEs comprised in the E-RAB SETUP REQUEST message are as defined in 36.413.

Table 2: E-RAB Setup Request IEs

IE/Group Name	Presence	Range	Semantics description	Criticality	Assigned Criticality
Message Type	M			YES	reject
UE Aggregate Maximum Bit Rate	O			YES	reject
E-RAB to be Setup List		1		YES	reject
>E-RAB To Be Setup Item IEs		1 to <maxnoof E-RABs>		EACH	reject
>>E-RAB ID	M			-	
>>E-RAB Level QoS Parameters	M		comprises necessary QoS parameters	-	
>>Transport Layer Address	M			-	
>>GTP-TEID	M			-	
>>NAS-PDU	M			-	

In Table 3 an example of IEs comprised in the E-RAB Setup Response is shown. The *Transport Layer Address* IE represents the IP address of the node where downlink traffic will need to be received by the booster eNB. Equivalently, the *GTP-TEID* IE represents the GTP tunnel endpoint ID assigned by the booster for the GTP tunnel corresponding to the E-RAB. The remaining IEs comprised in the E-RAB SETUP REQUEST message are as defined in 36.413.

Table 3: E-RAB Setup Response IEs

IE/Group Name	Presence	Range	Semantics description	Criticality	Assigned Criticality
Message Type	M			YES	reject
E-RAB Setup List		0..1		YES	ignore
>E-RAB Setup Item IEs		1 to <maxnoof E-RABs>		EACH	ignore
>>E-RAB ID	M			-	
>>Transport Layer Address	M			-	
>>GTP-TEID	M			-	
E-RAB Failed to Setup List	O		a value for E-RAB ID shall only be present once in E-RAB Setup List IE + in E-RAB Failed to Setup List IE	YES	ignore
Criticality Diagnostics	O			YES	ignore

Note that the E-RAB setup request that is sent from the anchor to a booster could be in response to a E-RAB setup request coming from the MME. That is, when the network wants to setup a bearer, it may contact the anchor node, and the anchor node, based on the criteria's discussed above, decides to setup the bearer on the anchor link or the booster link. If the booster link was chosen, then the anchor sends out the aforementioned E-RAB setup request to the booster node. Similarly, when the anchor gets an E-RAB setup response to such a request, it forwards the E-RAB setup response towards the network on behalf of the booster.

In order to address the cases where bearers are established at the booster node and need to be modified, E-RAB modify procedures between anchor node and booster node are introduced for application either via X2 interface or via a new interface. The basic procedure is shown in Figure 19.

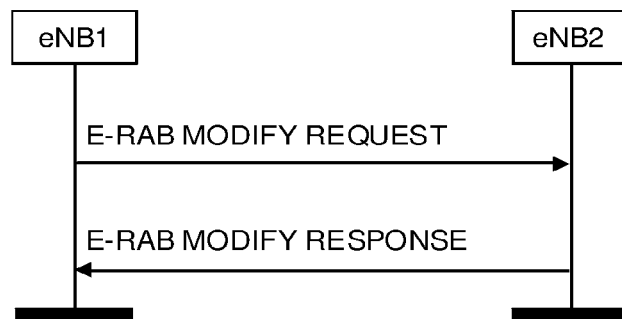


Figure 19: E-RAB Modify procedure

In Figure 19 eNB1 is the anchor node and eNB2 is the booster node. As an example, if the anchor node decides to modify bearers allocated to the booster node, then it will issue an E-RAB MODIFY REQUEST message. The booster node will reply with an E-RAB MODIFY RESPONSE message confirming whether the bearer has been successfully modified or whether the modification was not possible.

Table 4 shows the IEs that could be comprised in the E-RAB MODIFY REQUEST message. All the IEs are defined as in TS36.413.

Table 5 shows the IEs that could be comprised in the E-RAB MODIFY RESPONSE message. All IEs are defined as in TS36.413

Table 4: E-RAB Modify Request IEs

IE/Group Name	Presence	Range	Semantics description	Criticality	Assigned Criticality
Message Type	M			YES	reject
UE Aggregate Maximum Bit Rate	O			YES	reject
E-RAB to be Modified List		1		YES	reject
>E-RAB To Be Modified Item IEs		1 to <maxnoof E-RABs>		EACH	reject
>>E-RAB ID	M			-	
>>E-RAB Level QoS Parameters	M		Comprises necessary QoS parameters	-	
>>NAS-PDU	M			-	

Table 5: E-RAB Modify Response IEs

IE/Group Name	Presence	Range	Semantics description	Criticality	Assigned Criticality
Message Type	M			YES	reject
E-RAB Modify List		<i>0..1</i>		YES	ignore
>E-RAB Modify Item IEs		<i>1 to <maxnoof E-RABs></i>		EACH	ignore
>>E-RABID	M			-	
E-RAB Failed to Modify List	O		a value for <i>E-RAB ID</i> shall only be present once in <i>E-RAB Modify List</i> IE + <i>E-RAB Failed to Modify List</i> IE	YES	ignore
Criticality Diagnostics	O			YES	ignore

Note that, similar to the setting up of a bearer, the E-RAB MODIFY REQUEST that is sent from the anchor to a booster could be in response to an E-RAB MODIFY REQUEST coming from the MME. That is, when the network wants to modify a bearer, it may contact the anchor node, and the anchor node, when it finds out that the bearer is actually established on the booster link, sends out the aforementioned E-RAB MODIFY REQUEST to the booster node. Similarly, when the anchor gets an E-RAB MODIFY RESPONSE to such a request, it forwards it towards the network on behalf of the booster.

In case some bearers established at booster cell need to be removed, E-RAB Remove procedures are needed either via X2 or via a new interface between anchor and booster node.

Figure 20 shows an example of such procedure. In this procedure the anchor node, eNB1, takes a decision to remove one or more bearers established in the booster node and sends the E-RAB RELEASE COMMAND comprising a list of E-RABs to be released. The booster node, eNB2, replies with the E-RAB RELEASE RESPONSE indicating if the bearers were successfully removed.

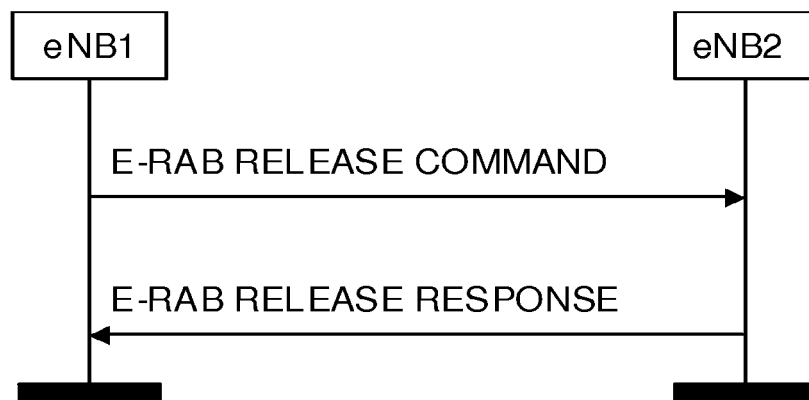


Figure 20: E-RAB Release procedure

Table 6 shows the IEs that could form the E-RAB RELEASE COMMAND, which are all defined in TS36.413.

Table 6: E-RAB Release Command IEs

IE/Group Name	Presence	Range	Semantics description	Criticality	Assigned Criticality
eNB UE S1AP ID	M			YES	reject
UE Aggregate Maximum Bit Rate	O			YES	reject
E-RAB To Be Released List	M		a value for E-RAB ID shall only be present once in E-RAB To Be Released List IE	YES	ignore
NAS-PDU	O			YES	ignore

Table 7 shows the IEs that could form the E-RAB RELEASE RESPONSE, which are all defined in TS36.413.

Table 7: E-RAB Release Command IEs

IE/Group Name	Presence	Range	Semantics description	Criticality	Assigned Criticality
eNB UE S1AP ID	M			YES	ignore
E-RAB Release List		<i>0..1</i>		YES	ignore
>E-RAB Release Item IEs		<i>1 to <maxnoof E-RABs></i>		EACH	ignore
>>E-RAB ID	M			-	
E-RAB Failed to Release List	O		a value for <i>E-RAB ID</i> shall only be present once in <i>E-RAB Release List IE + E-RAB Failed to Release List IE</i>	YES	ignore
Criticality Diagnostics	O			YES	ignore

Note that, similar to the setting up and modification of a bearer, the E-RAB RELEASE COMMAND that is sent from the anchor to a booster could be in response to an E-RAB RELEASE COMMAND coming from the MME. That is, when the network wants to release a bearer, it may contact the anchor node, and the anchor node, when it finds out that the bearer is actually established on the booster link, sends out the aforementioned E-RAB RELEASE COMMAND to the booster node. Similarly, when the anchor gets an E-RAB RELEASE RESPONSE to such a command, it forwards it towards the network on behalf of the booster.

It shall be noted that the E-RAB Setup Request, E-RAB Setup Response, E-RAB Modify Request, E-RAB Modify Response, E-RAB Release Request, E-RAB Release Response messages are already defined over the S1 interface between eNB and MME. However, according to some of the example embodiments, these messages are proposed for use over interfaces connecting eNBs, which makes the messages applicable to a different scenario and purposes.

In legacy LTE handover, after the completion of the handover at the target (i.e. the target gets the PATH SWITCH REQUEST ACK message from the MME), the target notifies this to the source by sending the UE Context Release message. When the source gets this message, it may release radio and control plane related resources associated to the UE context. However, with regard to selective handover, this might not be needed as some of the bearers of the UE might still be kept at the source.

According to some of the example embodiments, the source eNB, upon the reception of the context release message, will release only the resources associated with those bearers that have been selectively handed over.

According to some of the example embodiments, the procedures needed to learn the neighbour node and/or neighbour cells capability to support selective handovers are provided. Before initiating selective handover, it would be optimal if the source eNB could know whether the target eNB supports selective handover. If such information is available, the source eNB can choose to either trigger a selective handover towards the target or to trigger a legacy X2 based or S1 based handover procedure.

According to some of the example embodiments, an additional attribute, for example called “Selective HO Indication” is configured by the O&M system for each neighbour cell of an eNB during configuration of neighbour relationship table parameters (i.e. in addition to the currently existing “No remove”, “No X2” and “No HO” attributes, as specified in TS36.300). This parameter specifies whether the neighbour cell supports selective handover or not.

According to some of the example embodiments, the support for selective handover can be communicated directly between neighbouring eNBs during interface setup procedures. In case of existing X2 interface this can be achieved via inclusion of the *Selective Handover Indication* IE in the X2 SETUP REQUEST and X2 SETUP RESPONSE messages. The new IE may take values “supported” or “not-supported”. Additionally, the *Selective Handover Indication* IE can also be comprised in the eNB configuration update procedures. In the example of reuse of the X2 interface, this IE can be comprised in the eNB CONFIGURATION UPDATE REQUEST message. In the case of a new interface defined between neighbouring nodes, this embodiment is based on the presence of interface setup procedures and eNB configuration update procedures. Such procedures are shown in generalised graphs in Figure 21 and Figure 22. It shall be noted that the X2 interface has such procedures already specified in TS 23.423. However, Figure 21 and Figure 22 are interface independent and could be related to any new interface adopted.

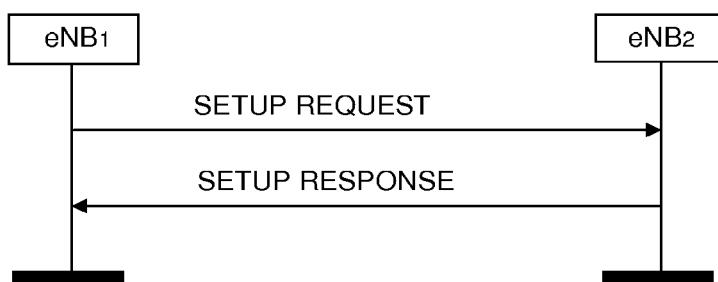


Figure 21: Generalized interface setup procedures

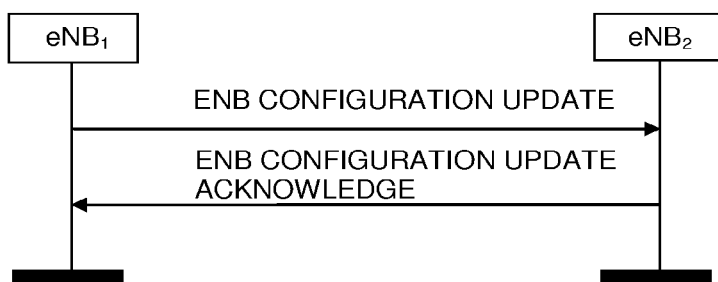


Figure 22: Generalised eNB configuration update procedures

Table 8 and Table 9 show the information elements that may constitute an X2 SETUP REQUEST and X2 SETUP RESPONSE message or that could constitute a new interface setup request and response message. It shall be noted the addition of the *Selective Handover Indication* IE with corresponding value range.

Table 8: Generalized list of IEs in interface setup request message

IE/Group Name	Presence	Range	Semantics description	Criticality	Assigned Criticality
Message Type	M			YES	reject
Global eNB ID	M			YES	reject
Served Cells		<i>1 .. <maxCellineNB></i>	Complete list of cells served by the eNB	YES	reject
>Served Cell Information	M			–	–
> Neighbour Information		<i>0 .. <maxnoofNeighbours></i>		–	–
>>ECGI	M		E-UTRAN Cell Global Identifier of the neighbour cell	–	–
>>PCI	M		Physical Cell Identifier of the neighbour cell	–	–
>>EARFCN	M		DL EARFCN for FDD and EARFCN for TDD	–	–
>>TAC	O		Tracking Area Code	YES	ignore
GU Group Id List		<i>0 .. <maxfPools></i>	This is all the pools to which the eNB belongs to	GLOBAL	reject
>GU Group Id	M			-	-
Selective Handover Indication	O	ENUMERATED (supported, not-supported, ...)	This IE indicates if the selective handover function is supported	–	–

Table 9: Generalized list of IEs in interface setup response message

IE/Group Name	Presence	Range	Semantics description	Criticality	Assigned Criticality
Message Type	M			YES	reject
Global eNB ID	M			YES	reject
Served Cells		<i>1 .. <maxCellineNB></i>	Complete list of cells served by the eNB	YES	reject
>Served Cell Information	M			–	–
>Neighbour Information		<i>0 .. <maxnoofNeighbours></i>		–	–
>>ECGI	M		E-UTRAN Cell Global Identifier of the neighbour cell	–	–
>>PCI	M		Physical Cell Identifier of the neighbour cell	–	–
>>EARFCN	M		DL EARFCN for FDD and EARFCN for TDD	–	–
>>TAC	O		Tracking Area Code	YES	ignore
GU Group Id List		<i>0 .. <maxPools></i>	This is all the pools to which the eNB belongs to	GLOBAL	reject
>GU Group Id	M			-	-
Criticality Diagnostics	O			YES	ignore
Selective Handover Indication	O	ENUMERATED (supported, not-supported, ...)	This IE indicates if the selective handover function is supported	–	–

Table 10 shows the information elements that may constitute an X2: eNB CONFIGURATION UPDATE message or that could constitute a new interface eNB configuration update message. It shall be noted the addition of the *Selective Handover Indication* IE with corresponding value range.

It has to be pointed out that in setup request, setup response and eNB configuration update messages, the *Selective Handover Indication* IE may alternatively be added as a cell attribute. Namely, the indication may be added for each cell listed in the *Served Cell Information* IE and for each cell listed in the *Neighbour Information* IE.

Table 10: Generalized list of IEs in eNB configuration update message

IE/Group Name	Presence	Range	Semantics description	Criticality	Assigned Criticality
Message Type	M			YES	reject
Served Cells To Add		0 .. <maxCellineNB>	Complete list of added cells served by the eNB	GLOBAL	reject
>Served Cell Information	M			–	–
> Neighbour Information		0 .. <maxnoofNeighbours>		–	–
>>ECGI	M		E-UTRAN Cell Global Identifier of the neighbour cell	–	–
>>PCI	M		Physical Cell Identifier of the neighbour cell	–	–
>>EARFCN	M		DL EARFCN for FDD and EARFCN for TDD	–	–
>>TAC	O		Tracking Area Code	YES	ignore
Served Cells To Modify		0 .. <maxCellineNB>	Complete list of modified cells served by the eNB	GLOBAL	reject
>Old ECGI	M		This is the old E-UTRAN Cell Global Identifier	-	-
>Served Cell Information	M			–	–
> Neighbour Information		0 .. <maxnoofNeighbours>		–	–
>>ECGI	M		E-UTRAN Cell Global Identifier of the neighbour cell	–	–
>>PCI	M		Physical Cell Identifier of the neighbour cell	–	–
>>EARFCN	M		DL EARFCN for FDD and EARFCN for TDD	–	–
>>TAC	O		Tracking Area Code	YES	ignore
>Deactivation Indication	O		Indicates the concerned cell is switched off for energy saving reasons	YES	ignore
Served Cells To Delete		0 .. <maxCellineNB>	Complete list of deleted cells served by the eNB	GLOBAL	reject
>Old ECGI	M		This is the old E-UTRAN Cell Global Identifier of the cell to be deleted	-	-
GU Group Id To Add List		0 .. <maxPools>		GLOBAL	reject
>GU Group Id	M			-	-
GU Group Id To Delete List		0 .. <maxPools>		GLOBAL	reject

>GU Group Id	M			-	-
Selective Handover Indication	O	<i>ENUMERATED (supported, not-supported, ...)</i>	This IE indicates if the selective handover function is supported	-	-

An alternative way to learn whether a neighbour eNB or cell supports selective handovers is to set criticality to “reject” for the new *Selective Handover* IE described as part of the handover preparation procedures. Namely if the target does not support selective handovers and cannot decode the *Selective Handover* IE, the handover procedure will be rejected. The source may take such procedure failure into account to build and maintain information about neighbour nodes not supporting selective handovers.

According to some of the example embodiments, new procedures are proposed for the exchange of RRC related information between anchor and booster eNBs. These procedures are introduced because, as described in previous parts of the example embodiments, it is assumed that the node hosting the RRC protocol termination is either the same node or it is connected to the anchor node. Therefore, it is not possible for the booster node to receive directly information signalled via the RRC protocol and neither it is possible for the booster node to configure specific UE behaviours at RRC level. However, as described in P38076 – selective handover lVD – it may be beneficial for the booster node to directly trigger handover procedures towards other neighbour cells. For this reason it would be beneficial to enable the booster node to receive Measurement Report information reported by the UE to the anchor node and to be able to provide measurement configuration to the anchor node, with the objective of signalling such measurement configuration via RRC to the UE.

In line with the above, the first procedure proposed either for use over the existing X2 interface or for use over a new interface is the RRC Information Report procedure shown in Figure 23.

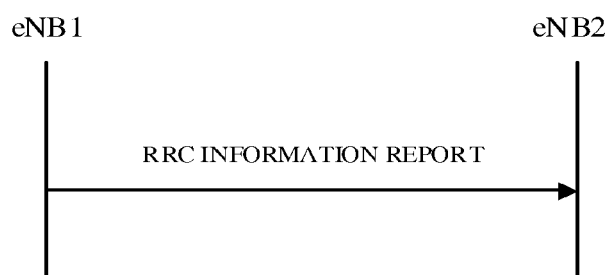


Figure 23: generalized procedure for reporting of RRC related information

In the RRC Information Report procedure the anchor node sends relevant RRC information to the booster node. Relevant RRC information may be Measurement Report messages received from UEs with a connection in both the anchor node and the booster node.

Additionally, the RRC INFORMATION REPORT message can also comprise other RRC messages for the purpose of sending such messages from the booster as well as from the anchor node. An example could be to comprise the content of the RRC Connection Reconfiguration with MobilityControlInfo, i.e. message 7 in Figure 14, in the RRC INFORMATION REPORT message. After receiving this message the booster node may decide to forward the information to the UE, therefore increasing the chances of correct reception of such information by the UE.

The RRC Information Report message may comprise a container IE similar to the *RRC Context* IE defined in TS36.423, where the IE may comprise the *MeasurementReport* message as defined in TS36.331 as well as other information exchanged over RRC with the UE. After receiving the information in the RRC Information Report message the booster node may take a decision to forward the information to the UE or to handover some or all the served UE bearers to a neighbour cell.

Alternatively, the RRC Information Report procedure may be following a request from the booster eNB. Such request may be specified in the form of an RRC Information Request message, as shown in Figure 24

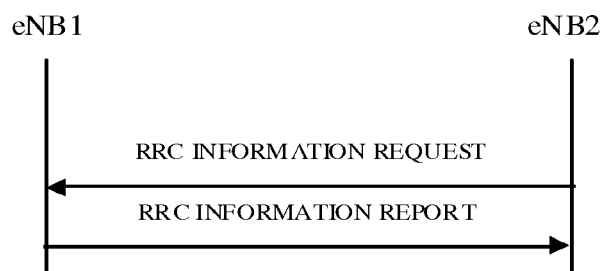


Figure 24: Generalized procedure for requesting and reporting of RRC related information

The second procedure proposed is the RRC Configuration procedure, which is made of an RRC Configuration Request and an RRC Configuration Response as shown in

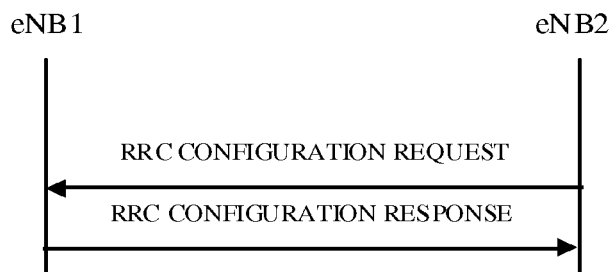


Figure 25.

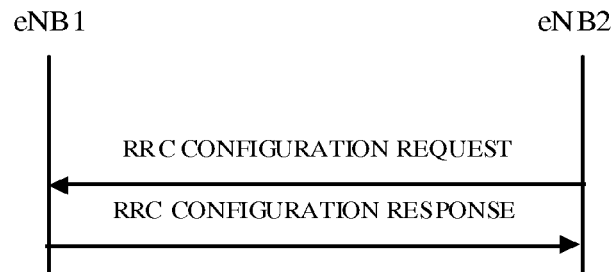


Figure 25: Generalized signaling for RRC configuration procedure

In the RRC Configuration Request message the booster eNB sends a particular RRC configuration that shall be signaled by the anchor eNB to the UE. The RRC Configuration Request message may comprise some or all the information elements used in RRC to configure UE measurements as specified in TS36.331.

Upon receiving an RRC Configuration Request message, the anchor eNB may decide to accept the RRC configuration and to configure the UE according to the information received from booster node. In this case the RRC Configuration Response will be sent from Anchor node to Booster node.

Alternatively, the anchor node may decide to reject the RRC configuration proposed by the booster node, in which case an RRC Configuration Failure message will be sent from Anchor node to Booster node.

An LTE system has been assumed throughout the discussion of the example embodiments. However, most of the ideas discussed above can become readily applicable to mobile broadband systems such as High Speed Packet Access (HSPA).

6 Example advantages of the example embodiments

The ideas discussed with respect to the example embodiments makes it possible to perform handovers selectively between a source and a target eNB, thereby creating more system flexibility than the legacy way of performing handover where a UE is completely handed over to the target. Some advantages of this are:

- Possibility to keep all the UE bearers ongoing as the bearers that the target was not able to admit can be kept at the source
- Possibility to trigger handover at a bearers level rather than at UE level. For example, the source eNB can keep the bearers that can't tolerate discontinuity such as VoIP services with itself until the radio conditions of the source are at much lower quality than the target, while bearers that are very capacity hungry but more tolerant to interruptions such as file download can be handed over to the target even if the radio conditions at the source are not that bad.
- Possibility to maintain control plane at one eNB, while sharing the data load at several eNBs. This opens several opportunities such as network sharing. For example, several operators can share the pico nodes for data bearers, while maintaining the signaling radio bearers only at their macros.

- Control plane diversity, such as sending of handover command from the source and/or targets or sending of the measurement report towards targets becomes rather straightforward with multiple connectivity.
- RLF on the booster or anchor node can be recovered faster. Booster recovery is straightforward as the UE context resides at the anchor, and anchor recovery also becomes fast as the booster can fetch the context easily from the network.

7 Figures

7.1 Example node configurations

The following example nodes may be configured to perform the example operations discussed herein.

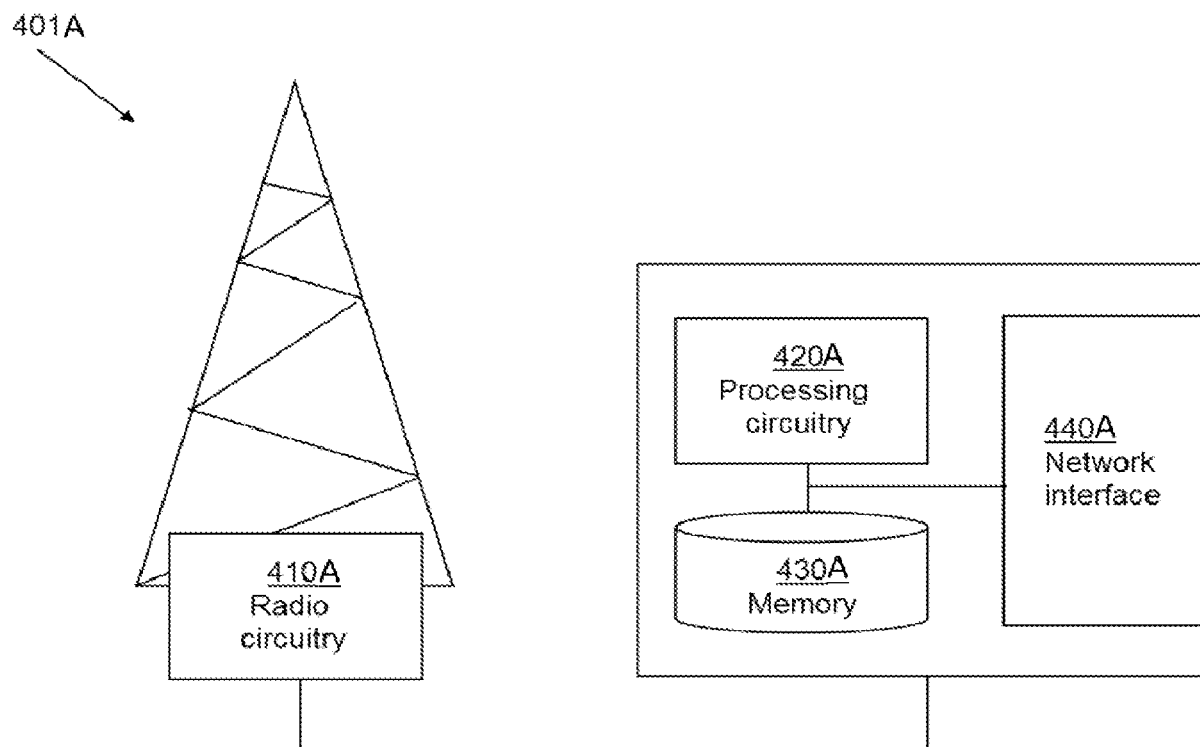


Figure 26 – Example configuration of a source base station

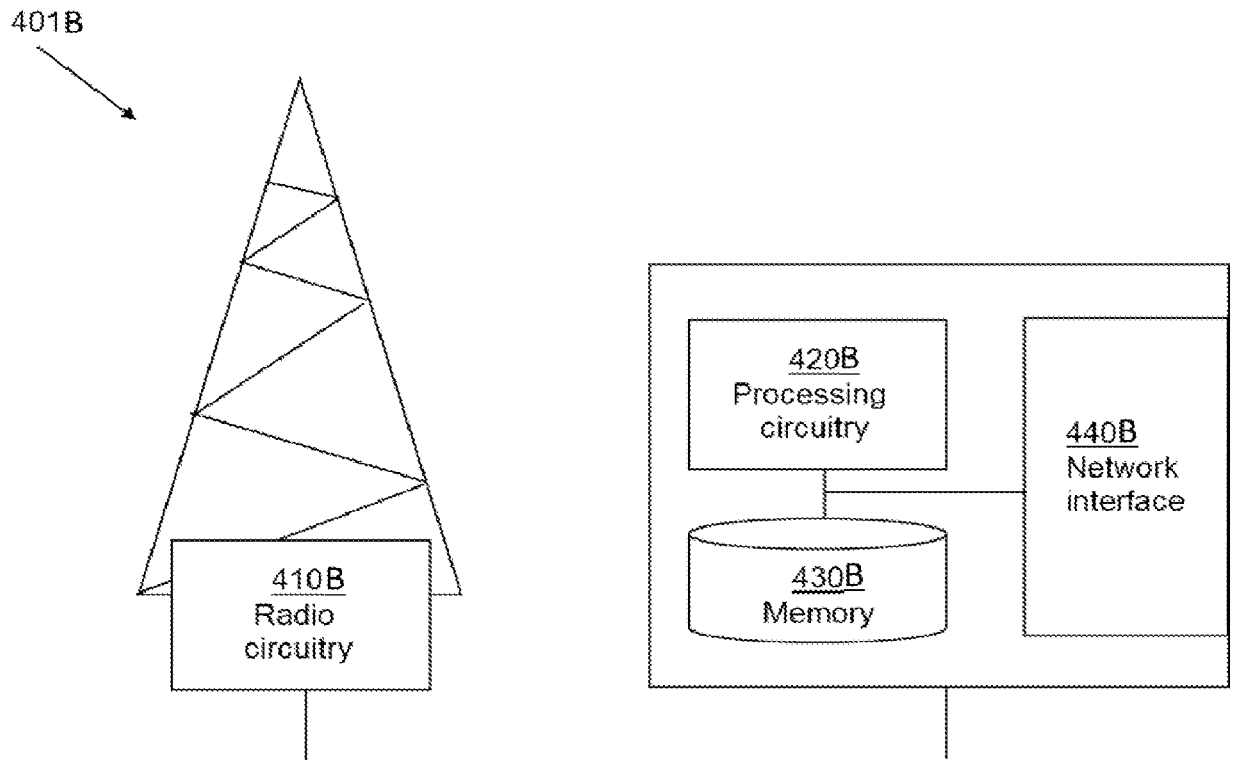


Figure 27 – Example configuration of a target base station

The example embodiments presented herein may be utilized in a wireless network, which may further comprise a source and target base station 401A and 401B, as illustrated in Figures 26 and 27, respectively. It should be appreciated that the examples provided in Figures 26 and 27 are shown merely as non-limiting examples.

As shown in Figure 26, the example source base station 401A may comprise processing circuitry 420A, a memory 430A, radio circuitry 410A, and at least one antenna. The processing circuitry 420A may comprise RF circuitry and baseband processing circuitry (not shown). In particular embodiments, some or all of the functionality described above as being provided by a mobile base station, a base station controller, a relay node, a NodeB, an enhanced NodeB, and/or any other type of mobile communications node may be provided by the processing circuitry 420A executing instructions stored on a computer-readable medium, such as the memory 430A shown in Figure 26.

Alternative embodiments of the source base station 401A may comprise additional components responsible for providing additional functionality, comprising any of the functionality identified above and/or any functionality necessary to support the solution described above. In other example embodiments, a network node may be not equipped with a radio interface or radio circuitry 410A.

It should also be appreciated that the processing circuitry (or any other hardware and/or software unit configured to execute operations and/or commands) of the source base station 401A illustrated in Figure 26 may be configured to configure to provide a selective handover procedure.

As shown in Figure 27, the example target base station 401B may comprise processing circuitry 420B, a memory 430B, radio circuitry 410B, and at least one antenna. The processing circuitry 420B may comprise RF circuitry and baseband processing circuitry (not shown). In particular embodiments, some or all of the functionality described above as being provided by a mobile base station, a base station controller, a relay node, a NodeB, an enhanced NodeB, and/or any other type of mobile communications node may be provided by the processing circuitry 420B executing instructions stored on a computer-readable medium, such as the memory 430B shown in Figure 27.

Alternative embodiments of the target base station 401B may comprise additional components responsible for providing additional functionality, comprising any of the functionality identified above and/or any functionality necessary to support the solution described above. In other example embodiments, a network node may be not equipped with a radio interface or radio circuitry 410B.

According to some of the example embodiments, the source base station may be functioning as either a booster or anchor node, while the target base station may also function as either a booster or anchor node. Thus, according to some of the example embodiments, the selective handover procedure may take place from an anchor (source) to a booster (target) node, from a booster (source) node to another booster (target) node, or from a booster (source) node to an anchor (target) node.

7.2 Flow diagrams

It should be appreciated that the terms ‘source base station’ and ‘target base station’ have been used to describe the example embodiments herein. It should be appreciated that the source and target in general may be thought of as cells. However, it is the base stations which send the messages described herein on behalf of their respective cells.

Figure 28 is a flow diagram depicting example operations which may be taken by the source base station 401A of Figure 26 in the providing a handover of at least a sub-set of bearers associated with a user equipment. It should also be appreciated that Figure 28 comprises some operations which are illustrated with a darker border and some operations which are illustrated with a lighter border. The operations which are comprised in a darker border are operations which are comprised in the broadest example embodiment. The operations which are comprised in a lighter border are example embodiments which may be comprised in, or a part of, or are further operations which may be taken in addition to the operations of the boarder example embodiments. It should be appreciated that these operations need not be performed in order. Furthermore, it should be appreciated that not all of the operations need to be performed. The example operations may be performed in any order and in any combination.

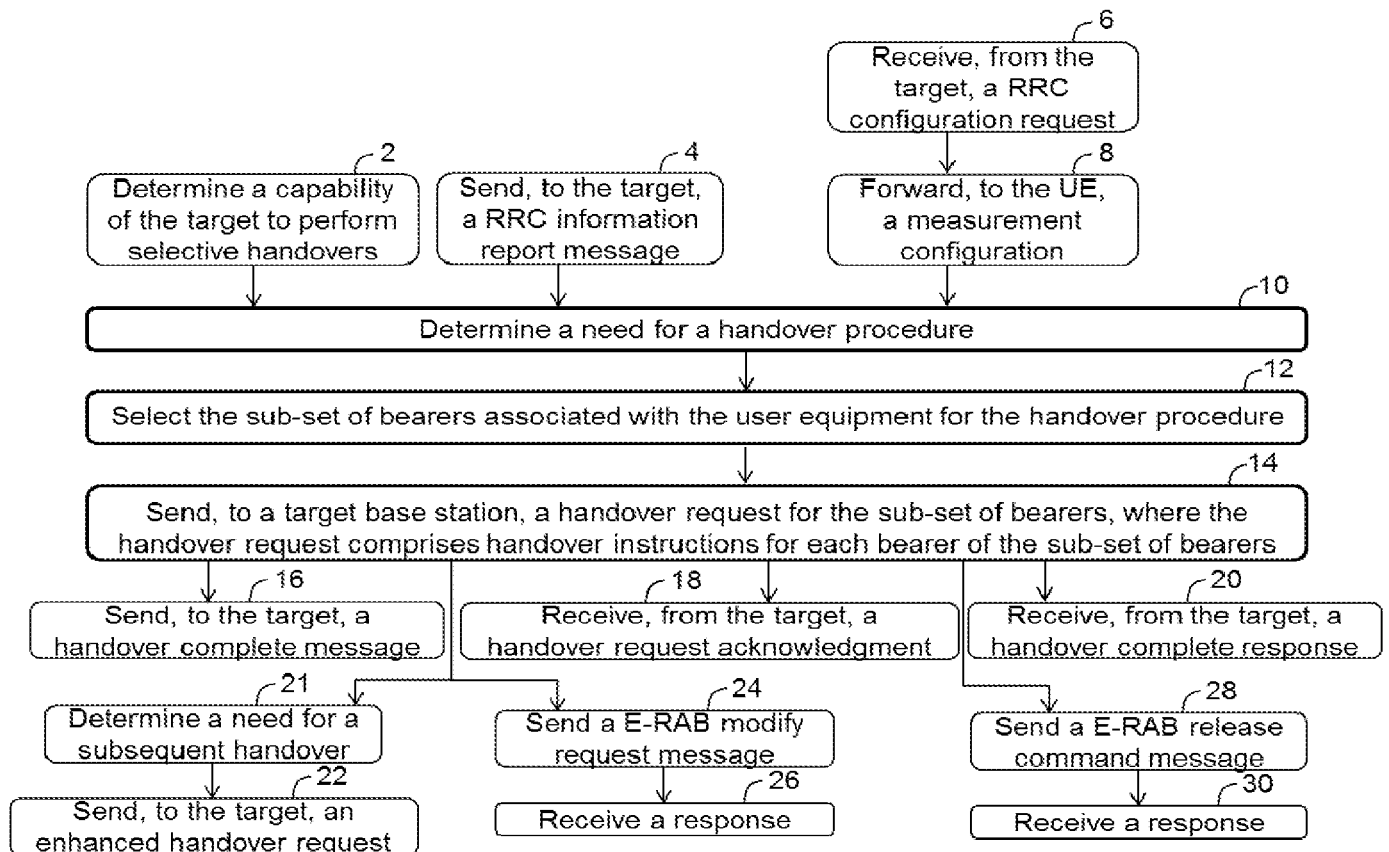


Figure 28 – flow diagram of example operations of a source base station

Figure 29 is a flow diagram depicting example operations which may be taken by the target base station 401B of Figure 27 in the providing a handover of at least a sub-set of bearers associated with a user equipment. It should also be appreciated that Figure 29 comprises some operations which are illustrated with a darker border and some operations which are illustrated with a lighter border. The operations which are comprised in a darker border are operations which are comprised in the broadest example embodiment. The operations which are comprised in a lighter border are example embodiments which may be comprised in, or a part of, or are further operations which may be taken in addition to the operations of the boarder example embodiments. It should be appreciated that these operations need not be performed in order. Furthermore, it should be appreciated that not all of the operations need to be performed. The example operations may be performed in any order and in any combination.

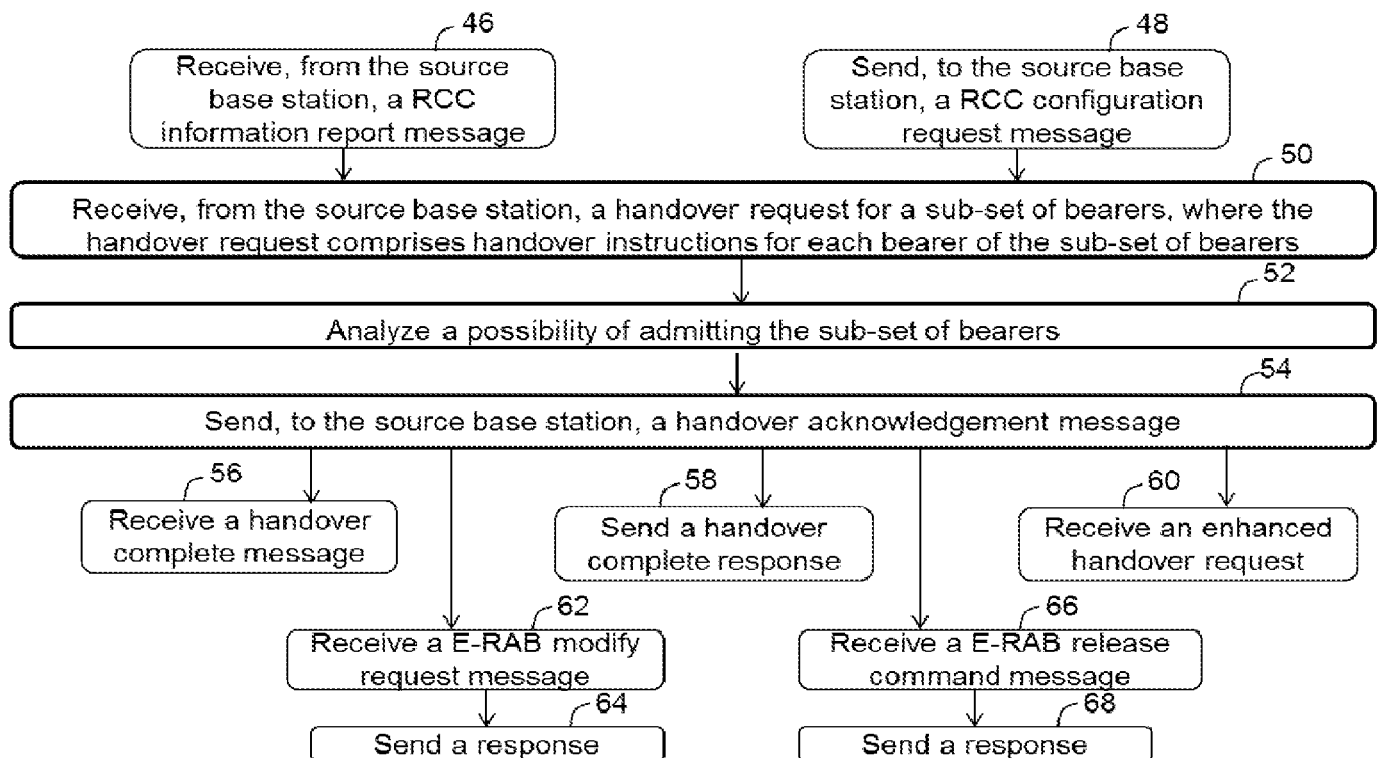


Figure 29 – flow diagram of example operations of a target base station

8 Conclusion

It should be noted that although terminology from 3GPP LTE has been used herein to explain the example embodiments, this should not be seen as limiting the scope of the example embodiments to only the aforementioned system. Other wireless systems, comprising WCDMA, WiMax, UMB, WiFi and GSM, may also benefit from the example embodiments disclosed herein.

The description of the example embodiments provided herein have been presented for purposes of illustration. The description is not intended to be exhaustive or to limit example embodiments to the precise form disclosed, and modifications and variations are possible in light of the above teachings or may be acquired from practice of various alternatives to the provided embodiments. The examples discussed herein were chosen and described in order to explain the principles and the nature of various example embodiments and its practical application to enable one skilled in the art to utilize the example embodiments in various manners and with various modifications as are suited to the particular use contemplated. The features of the embodiments described herein may be combined in all possible combinations of methods, apparatus, modules, systems, and computer program products. It should be appreciated that the example embodiments presented herein may be practiced in any combination with each other.

It should be noted that the word “comprising” does not necessarily exclude the presence of other elements or steps than those listed and the words “a” or “an” preceding an element do not exclude the presence of a plurality of such elements. It should further be noted that any reference signs do not limit the scope of the claims, that the example embodiments may be implemented at least in part by means of both hardware and software, and that several “means”, “units” or “devices” may be represented by the same item of hardware.

Also note that terminology such as user equipment should be considered as non-limiting. A device or user equipment as the term is used herein, is to be broadly interpreted to comprise a radiotelephone having ability for Internet/intranet access, web browser, organizer, calendar, a camera (e.g., video and/or still image camera), a sound recorder (e.g., a microphone), and/or global positioning system (GPS) receiver; a personal communications system (PCS) user equipment that may combine a cellular radiotelephone with data processing; a personal digital assistant (PDA) that can comprise a radiotelephone or wireless communication system; a laptop; a camera (e.g., video and/or still image camera) having communication ability; and any other computation or communication device capable of transceiving, such as a personal computer, a home entertainment system, a television, etc. It should be appreciated that the term user equipment may also comprise any number of connected devices.

The various example embodiments described herein are described in the general context of method steps or processes, which may be implemented in one aspect by a computer program product, embodied in a computer-readable medium, comprising computer-executable instructions, such as program code, executed by computers in networked environments. A computer-readable medium may comprise removable and non-removable storage devices comprising, but not limited to, Read Only Memory (ROM), Random Access Memory (RAM), compact discs (CDs), digital versatile discs (DVD), etc. Generally, program modules may comprise routines, programs, objects, components, data structures, etc. that perform particular tasks or implement particular abstract data types. Computer-executable instructions, associated data structures, and program modules represent examples of program code for executing steps of the methods disclosed herein. The particular sequence of such executable instructions or associated data structures represents examples of corresponding acts for implementing the functions described in such steps or processes.

In the drawings and specification, there have been disclosed exemplary embodiments. However, many variations and modifications can be made to these embodiments. Accordingly, although specific terms are employed, they are used in a generic and descriptive sense only and not for purposes of limitation, the scope of the embodiments being defined by the following summary of example embodiments.

9 Abbreviations

3GPP	3 rd Generation Partnership Project
AMBR	Aggregate Maximum Bit Rate
AP	Application Protocol
ARP	Allocation and Retention Priority
ARQ	Automatic Repeat reQuest
BCH	Broadcast Channel
CIO	Cell Individual Offset
CN	Core Network
CRS	Cell specific Reference Symbol
CSG	Closed Subscriber Group
DL	Downlink
DM	Demodulation
DRB	Data Radio Bearer
E-UTRAN	Evolved UMTS Terrestrial Radio Access Network
eNB/eNodeB	enhanced Node B(base station)
EPC	Evolved Packet Core
EPS	Evolved Packet System
GBR	Guaranteed Bit Rate
GUMMEI	Globally Unique Mobility Management Entity Identifier
HARQ	Hybrid Automatic Repeat reQuest
HeNB	Home eNB
HO	Handover
HOM	Handover Margin
HSPA	High-Speed Packet Access
IE	Information Element
ID	Identity
IP	Internet Protocol
LTE	Long Term Evolution
MAC	Medium Access Control
MBR	Maximum Bit Rate
MME	Mobility Management Entity
MTCP	Multi-path Transmission Control Protocol
NAS	Non-Access Stratum

OAM	Operation and Maintenance
P-GW	PDN Gateway
PBCH	Physical Broadcast CHannel
PCell	Primary Cell
PCFICH	Physical Control Format Indicator CHannel
PCI	Physical Cell Identity
PDCCH	Physical Downlink Control CHannel
PDCP	Packet Data Convergence Protocol
PDN	Packet Data Network
PDSCH	Physical Downlink Shared CHannel
PDU	Packet Data Unit
PHICH	Physical Hybrid ARQ Indicator CHannel
PSS	Primary Synchronization Signal
QCI	QoS Class Identifier
QoS	Quality of Service
RLC	Radio Link Control
RAB	Radio Access Bearer
RAT	Radio Access Technology
RE	Resource Element
RRC	Radio Resource Control
RRH	Remote Radio Head
RRM	Radio Resource Management
RS	Reference Signal
RSCP	Received Signal Code Power
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
S-GW	Serving Gateway
SCell	Secondary Cell
SCTP	Stream Control Transmission Protocol
SDF	Service Data Flow
SDU	Service Data Unit
SRB	Signaling Radio Bearer
SRVCC	Single Radio Voice Call Continuity
SSS	Secondary Synchronization Signal
TCP	Transmission Control Protocol
TTT	Time To Trigger
UE	User Equipment
UL	Uplink
VoIP	Voice over Internet Protocol

10 Summary of example embodiments

In some instances, the summary of example embodiments provides specific names for messages and information elements which are passed throughout the network. It should be appreciated that such names are used merely as an examples. One purpose of the summary of example embodiments is to highlight the function of such messages and information elements. It should further be appreciated that any messages mentioned herein may be applied to any new or existing interface of the wireless network.

1. A method, in a source base station, for providing a handover of at least a sub-set of bearers associated with a user equipment, the method comprising:
 - determining **(10)** a need for a handover procedure;
 - selecting **(12)** the sub-set of bearers associated with the user equipment for the handover procedure; and
 - sending **(14)**, to a target base station, a handover request for the sub-set of bearers, wherein the handover request comprises handover instructions for each bearer of the sub-set of bearers.
2. The method of example embodiment 1, further comprising sending **(16)**, to the target base station, a handover complete message upon a completion of the handover procedure.
3. The method of any of example embodiments 1-2, wherein the handover request and/or the handover complete message comprise an information element, said information element comprising any one of the following:
 - An indication that the message is an *RRCConnectionReconfigurationComplete* message as defined in TS36.331.
 - User equipment specific identifications for the bearers handed over.
 - Specific identification for the handover preparation procedure to which the message corresponds to.
 - An indication as to whether the handover was completed successfully or whether it failed to complete.

By taking the X2 HANDOVER REQUEST message as an example, some of the example embodiments may comprise letting the target base station be informed that a given handover is a selective handover rather than a legacy handover (e.g., a full handover after which the user equipment connection is kept in one cell only) by introducing a new optional IE (e.g., 'selective handover') in the HANDOVER REQUEST message. This IE

may take different values depending on the type of selective handover that is being requested.

For example, it may have three values, a value of “0” referring to “data radio bearers” (meaning only the data radio bearers listed in the E-RAB list are to be handed over) or value “1” referring to “signalling radio bearers” (meaning only the signalling radio bearers listed in the E-RAB list are to be handed over) or it may have the value “2” referring to “signalling and data radio bearers” (meaning signalling radio bearers as well as the data radio bearers comprised in the E-RAB list are to be handed over). The Selective Handover IE can also be comprised inside the RRC Context IE, which is also comprised in the X2: HANDOVER REQUEST message. “

According to some of the example embodiments, the information element may also indicate that a full handover procedure was unsuccessful and thus a selective handover procedure was performed where the bearers that were not comprised in the selective handover procedure will remain associated with the source base station.

According to some of the example embodiments, the information element may provide information on a per bearer basis.

According to some of the example embodiments, the handover request message may contain the full list of bearers associated with the UE, each bearer being provided with an indication of whether it needs to be handed over to the target or whether it needs to continue being served by the source. In another example embodiment, the handover request message may contain two lists of bearers, one including bearers that need to be handed over to the target and one that needs to continue being served by the source.

According to some of the example embodiments, the handover request message can be sent from a booster node to either indicate bearers that need to be handed over back to the anchor or to indicate bearers that should be handed over to a different booster.

According to another example embodiment, if the booster triggers an handover to the anchor with the purpose of indicating that bearers are handed over to a different booster, the handover request message may be enhanced with new IEs to indicate the identity of the new booster cell.

4. The method of any of example embodiments 1-3, further comprising receiving **(20)**, from the target base station, a handover complete response message, said handover complete response message comprising at least one information element on a result of the handover procedure.

According to some of the example embodiments, if the handover is unsuccessful, the information element may further comprise a cause code specifying the reason for the failure.

According to some of the example embodiments, the information element may provide information

on a per bearer basis. According to some of the example embodiments, the information elements may comprise a list of non-admitted bearers.

5. The method of any of example embodiments 1-4, wherein the handover request comprises an information element indicating that the handover procedure is a selective handover procedure.
6. The method of any of example embodiments 1-5, further comprising receiving **(18)**, from the target base station, a handover request acknowledgement, said handover request acknowledgement comprising an information element providing a result of a setup of the handover procedure.

According to some of the example embodiments, the information element may provide information on a per bearer basis.

According to some of the example embodiments, upon reception of the HANDOVER REQUEST ACKNOWLEDGE and of the E-RABs Not Admitted List, the anchor base station may decide to maintain the non-admitted bearers active and to keep on serving the user equipment with these bearers traffic.

7. The method of any of example embodiments 1-6, further comprising sending **(22)**, to the target base station, enhanced handover request and enhanced handover complete messages for a subset of bearers in a subsequent selective handover procedure.

It should be appreciated that the successive selective handovers may be for the purpose of moving more bearers to/from the booster base station. If bearers need to be handed over from booster to anchor, the booster may initiate the selective handover procedures and send the Handover Request message.

8. The method of example embodiment 7, wherein the enhanced handover request and enhanced handover complete messages further comprises an E-RAB setup request and E-RAB setup response, respectively.

According to some of the example embodiments, the E-RAB setup request may be a consequence of an E-RAB setup request sent from the core network to the anchor node.

According to some of the example embodiments, the E-RAB setup request may comprise information with respect to bearers which need to be setup at the target base station.

According to some of the example embodiments, the E-RAB setup response may comprise information with respect to a result of the subsequent selective handover.

It should be appreciated that both the E-RAB setup request and E-RAB setup response may comprise information on a per bearer basis.

9. The method of any of example embodiments 7-8, wherein further comprising determining **(21)** a need for a subsequent handover procedure.

According to some of the example embodiments, the determining may be based on any one of the following criteria:

- User equipment radio conditions monitored via reception of measurement reports by the user equipment-
- Load related conditions, i.e., whether the serving anchor cell is in need to offload traffic to a booster cell.
- Performance related conditions, i.e., whether it is more opportune for some bearers to be served by the booster cell due to the improved performance the booster node could provide (e.g. in case of bearers with predominant uplink traffic).

It shall be appreciated that in legacy handover procedures a handover execution is followed by a UE context release message aimed at removing the UE context from the source eNB. In one example embodiment, after a selective handover only the resources relative to the bearers selectively handed over are removed from the source node.

10. The method of any of example embodiments 1-9, further comprises sending **(24)**, to the target base station, a E-RAB modify request message, said E-RAB modify request message comprising information on how to modify at least one bearer which is established at the target base station.

According to some of the example embodiments, the E-RAB modify request may be a consequence of an E-RAB modify request sent from the core network to the anchor node.

11. The method of example embodiment 10, further comprising receiving **(26)**, from the target base station, a E-RAB modify response message, said E-RAB modify response message comprising information on a result of a modification to the at least one bearer.

12. The method of any of example embodiments 1-9, further comprises sending **(28)**, to the target base station, a E-RAB release command message, said E-RAB release command message comprising instructions to release at least one bearer which is established at the target base station.

According to some of the example embodiments, the E-RAB release request may be a consequence of an E-RAB release request sent from the core network to the anchor node.

13. The method of example embodiment 12, further comprising receiving **(30)**, from the target base station, a E-RAB release response message, said E-RAB release response message comprising information on a result of a release of the at least one bearer.

It should be appreciated that example embodiments 10-13 describe E-RAB management procedures between two base stations. According to some of the example embodiments, both the target and source base stations may trigger such procedures.

14. The method of any of example embodiments 1-13, further comprising determining **(2)** a capability of the target base station to perform selective handover procedures.

According to some of the example embodiments, the capability may be determined via a configuration by an O&M system for each neighbour cell of a base station during configuration of neighbour relationship table parameters.

According to some of the example embodiments, the capability may be determined via an interface setup procedure between neighbouring base stations. Example messages where such information may be supplied are X2 SETUP REQUEST, X2 SETUP RESPONSE, and/or a CONFIGURATION UPDATE REQUEST message. It should further be appreciated that the example embodiments may be applied to any new interfaces

According to some of the example embodiments, the source base station may also determine the capability by keeping a record of base stations which reject a request for a partial handover procedure.

15. The method of any of example embodiments 1-14, further comprising sending **(4)**, to the target base station, a RRC information report message.

According to some of the example embodiments, RRC information may comprise measurement report messages received from a user equipment.

According to some of the example embodiments, the RRC information report message may be sent as a result of a request from the target base station.

According to some of the example embodiments, the RRC INFORMATION REPORT message may also comprise other RRC messages for the purpose of sending such messages from the booster as well as from the anchor node. An example may comprise the content of the RRC Connection Reconfiguration with *MobilityControlInfo* in the RRC INFORMATION REPORT message. After receiving this message the booster node may decide to forward the information to the user equipment, therefore increasing the chances of correct reception of such information by the user equipment.

16. The method of any of example embodiments 1-15, further comprising receiving **(6)**, from the target base station, a RCC CONFIGURATION REQUEST message, said RCC CONFIGURATION REQUEST message comprising a user equipment measurement configuration.

According to some of the example embodiments, the source base station may send a RCC CONFIGURATION RESPONSE to the target base station providing the target base station with the decision made with respect to the RCC CONFIGURATION REQUEST.

17. The method of example embodiment 16, further comprising forwarding (8), to the user equipment, a measurement configuration according to the RCC CONFIGURATION REQUEST message.
18. A source base station for providing a handover of at least a sub-set of bearers associated with a user equipment, the source base station comprising:
 - processing circuitry (420A) configured to determine a need for a handover procedure;
 - the processing circuitry (420A) further configured to select the sub-set of bearers associated with the user equipment for the handover procedure; and
 - radio circuitry (410A) configured to send, to a target base station, a handover request for the sub-set of bearers, wherein the handover request comprises handover instructions for each bearer of the sub-set of bearers.
19. The source base station of example embodiment 18, wherein the radio circuitry (410A) is further configured to send, to the target base station, a handover complete message upon a completion of the handover procedure.
20. The source base station of any of example embodiments 18-19, wherein the handover request and/or the handover complete message comprise an information element, said information element comprising any one of the following:
 - An indication that the message is an *RRCConnectionReconfigurationComplete* message as defined in TS36.331.
 - User equipment specific identifications for the bearers handed over.
 - Specific identification for the handover preparation procedure to which the message corresponds to.
 - An indication as to whether the handover was completed successfully or whether it failed to complete.

By taking the X2 HANDOVER REQUEST message as an example, some of the example embodiments may comprise letting the target base station be informed that a given handover is a selective handover rather than a legacy handover (e.g., a full handover after which the user equipment connection is kept in one cell only) by introducing a new optional IE (e.g., 'selective handover') in the HANDOVER REQUEST message. This IE may take different values depending on the type of selective handover that is being requested.

For example, it may have three values, a value of “0” referring to “data radio bearers” (meaning only the data radio bearers listed in the E-RAB list are to be handed over) or value “1” referring to “signalling radio bearers” (meaning only the signalling radio bearers listed in the E-RAB list are to be handed over) or it may have the value “2” referring to “signalling and data radio bearers” (meaning signalling radio bearers as well as the data radio bearers comprised in the E-RAB list are to be handed over). The Selective Handover IE can also be comprised inside the RRC Context IE, which is also comprised in the X2: HANDOVER REQUEST message. “

According to some of the example embodiments, the information element may also indicate that a full handover procedure was unsuccessful and thus a selective handover procedure was performed where the bearers that were not comprised in the selective handover procedure will remain associated with the source base station.

According to some of the example embodiments, the information element may provide information on a per bearer basis.

According to some of the example embodiments, the handover request message may contain the full list of bearers associated with the UE, each bearer being provided with an indication of whether it needs to be handed over to the target or whether it needs to continue being served by the source. In another example embodiment, the handover request message may contain two lists of bearers, one including bearers that need to be handed over to the target and one that needs to continue being served by the source.

According to some of the example embodiments, the handover request message can be sent from a booster node to either indicate bearers that need to be handed over back to the anchor or to indicate bearers that should be handed over to a different booster.

According to another example embodiment, if the booster triggers an handover to the anchor with the purpose of indicating that bearers are handed over to a different booster, the handover request message may be enhanced with new IEs to indicate the identity of the new booster cell.

21. The source base station of any of example embodiments 18-20, wherein the radio circuitry **(410A)** is further configured to receive, from the target base station, a handover complete response message, said handover complete response message comprising at least one information element on a result of the handover procedure.

According to some of the example embodiments, if the handover is unsuccessful, the information element may further comprise a cause code specifying the reason for the failure. According to some of the example embodiments, the information element may provide information on a per bearer basis. According to some of the example embodiments, the information elements may comprise a list of non-admitted bearers.

22. The source base station of any of example embodiments 18-21, wherein the handover request comprises an information element indicating that the handover procedure is a selective handover procedure.
23. The source base station of any of example embodiments 18-22, wherein the radio circuitry **(410A)** is further configured to receive, from the target base station, a handover request acknowledgement, said handover request acknowledgement comprising an information element providing a result of a setup of the handover procedure.

According to some of the example embodiments, the information element may provide information on a per bearer basis.

According to some of the example embodiments, upon reception of the HANDOVER REQUEST ACKNOWLEDGE and of the E-RABs Not Admitted List, the anchor base station may decide to maintain the non-admitted bearers active and to keep on serving the user equipment with these bearers traffic.

24. The source base station of any of example embodiments 18-23, wherein the radio circuitry **(410A)** is further configured to send, to the target base station, enhanced handover request and enhanced handover complete messages for a sub-set of bearers in a subsequent selective handover procedure.

It should be appreciated that the successive selective handovers may be for the purpose of moving more bearers to/from the booster base station. If bearers need to be handed over from booster to anchor, the booster may initiate the selective handover procedures and send the Handover Request message.

25. The source base station of example embodiment 24, wherein the enhanced handover request and enhanced handover complete messages further comprises an E-RAB setup request and E-RAB setup response, respectively.

According to some of the example embodiments, the E-RAB setup request may be a consequence of an E-RAB setup request sent from the core network to the anchor node.

According to some of the example embodiments, the E-RAB setup request may comprise information with respect to bearers which need to be setup at the target base station.

According to some of the example embodiments, the E-RAB setup response may comprise information with respect to a result of the subsequent selective handover.

It should be appreciated that both the E-RAB setup request and E-RAB setup response may comprise information on a per bearer basis.

26. The source base station of any of example embodiments 24-25, wherein the processing circuitry **(420A)** is further configured to determine a need for a subsequent handover procedure.

According to some of the example embodiments, the determining may be based on any one of the following criteria:

- User equipment radio conditions monitored via reception of measurement reports by the user equipment-
- Load related conditions, i.e., whether the serving anchor cell is in need to offload traffic to a booster cell.
- Performance related conditions, i.e., whether it is more opportune for some bearers to be served by the booster cell due to the improved performance the booster node could provide (e.g. in case of bearers with predominant uplink traffic).

It shall be appreciated that in legacy handover procedures an handover execution is followed by a UE context release message aimed at removing the UE context from the source eNB. In one example embodiment, after a selective handover only the resources relative to the bearers selectively handed over are removed from the source node.

27. The source base station of any of example embodiments 18-26, wherein the radio circuitry **(410A)** is further configured to send, to the target base station, an E-RAB modify request message, said E-RAB modify request message comprising information on how to modify at least one bearer which is established at the target base station.

According to some of the example embodiments, the E-RAB modify request may be a consequence of an E-RAB modify request sent from the core network to the anchor node.

28. The source base station of example embodiment 27, wherein the radio circuitry **(410A)** is further configured to receive, from the target base station, an E-RAB modify response message, said E-RAB modify response message comprising information on a result of a modification to the at least one bearer.

29. The source base station of any of example embodiments 18-26, wherein the radio circuitry **(410A)** is further configured to send, to the target base station, an E-RAB release command message, said E-RAB release command message comprising instructions to release at least one bearer which is established at the target base station.

According to some of the example embodiments, the E-RAB release request may be a consequence of an E-RAB release request sent from the core network to the anchor node

30. The source base station of example embodiment 29, wherein the radio circuitry **(410A)** is further configured to receive, from the target base station, an E-RAB release response message, said E-

RAB release response message comprising information on a result of a release of the at least one bearer.

It should be appreciated that example embodiments 27-30 describe E-RAB management procedures between two base stations. According to some of the example embodiments, both the target and source base stations may trigger such procedures.

31. The source base station of any of example embodiments 18-30, wherein the processing circuitry **(420A)** is further configured to determine a capability of the target base station to perform selective handover procedures.

According to some of the example embodiments, the capability may be determined via a configuration by an O&M system for each neighbour cell of a base station during configuration of neighbour relationship table parameters.

According to some of the example embodiments, the capability may be determined via an interface setup procedure between neighbouring base stations. Example messages where such information may be supplied are X2 SETUP REQUEST, X2 SETUP RESPONSE, and/or a CONFIGURATION UPDATE REQUEST message. It should further be appreciated that the example embodiments may be applied to any new interfaces

According to some of the example embodiments, the source base station may also determine the capability by keeping a record of base stations which reject a request for a partial handover procedure.

32. The source base station of any of example embodiments 18-31, wherein the radio circuitry **(410A)** is further configured to send, to the target base station, a RRC information report message.

According to some of the example embodiments, RRC information may comprise measurement report messages received from a user equipment.

According to some of the example embodiments, the RRC information report message may be sent as a result of a request from the target base station.

According to some of the example embodiments, the RRC INFORMATION REPORT message may also comprise other RRC messages for the purpose of sending such messages from the booster as well as from the anchor node. An example may comprise the content of the RRC Connection Reconfiguration with *MobilityControlInfo* in the RRC INFORMATION REPORT message. After receiving this message the booster node may decide to forward the information to the user equipment, therefore increasing the chances of correct reception of such information by the user equipment.

33. The source base station of any of example embodiments 18-32, wherein the radio circuitry **(410A)** is further configured to receive, from the target base station, a RCC CONFIGURATION REQUEST

message, said RCC CONFIGURATION REQUEST message comprising a user equipment measurement configuration.

According to some of the example embodiments, the source base station may send a RCC CONFIGURATION RESPONSE to the target base station providing the target base station with the decision made with respect to the RCC CONFIGURATION REQUEST.

34. The source base station of example embodiment 33, wherein the radio circuitry **(410A)** is further configured to send, to the user equipment, a measurement configuration according to the RCC CONFIGURATION REQUEST message.
35. A method, in a target base station, for providing a handover of at least a sub-set of bearers associated with a user equipment, the method comprising:
 - receiving **(50)**, from a source base station, a handover request for the sub-set of bearers associated with the user equipment wherein the handover request comprises handover instructions for each bearer of the sub-set of bearers;
 - analysing **(52)** a possibility of the sub-set of bearers being admitted in the handover; and
 - sending **(54)**, to the source base station, a handover request acknowledgement comprising a result of the analysing.
36. The method of example embodiment 35, further comprising receiving **(56)**, from the source base station, a handover complete message upon a completion of the handover procedure.
37. The method of any of example embodiments 35-36, wherein the handover request and/or the handover complete message comprise an information element, said information element comprising any one of the following:
 - An indication that the message is an *RRConnectionReconfigurationComplete* message as defined in TS36.331.
 - User equipment specific identifications for the bearers handed over.
 - Specific identification for the handover preparation procedure to which the message corresponds to.
 - An indication as to whether the handover was completed successfully or whether it failed to complete.

By taking the X2 HANDOVER REQUEST message as an example, some of the example embodiments may comprise letting the target base station be informed that a given handover is a selective handover rather than a legacy handover (e.g., a full handover after which the user equipment connection is kept in one cell only) by introducing a new optional IE (e.g., 'selective handover') in the HANDOVER REQUEST message. This IE

may take different values depending on the type of selective handover that is being requested.

For example, it may have three values, a value of “0” referring to “data radio bearers” (meaning only the data radio bearers listed in the E-RAB list are to be handed over) or value “1” referring to “signalling radio bearers” (meaning only the signalling radio bearers listed in the E-RAB list are to be handed over) or it may have the value “2” referring to “signalling and data radio bearers” (meaning signalling radio bearers as well as the data radio bearers comprised in the E-RAB list are to be handed over). The Selective Handover IE can also be comprised inside the RRC Context IE, which is also comprised in the X2: HANDOVER REQUEST message.

According to some of the example embodiments, the handover request message may contain the full list of bearers associated with the UE, each bearer being provided with an indication of whether it needs to be handed over to the target or whether it needs to continue being served by the source. In another example embodiment, the handover request message may contain two lists of bearers, one including bearers that need to be handed over to the target and one that needs to continue being served by the source.

According to some of the example embodiments, the handover request message can be sent from a booster node to either indicate bearers that need to be handed over back to the anchor or to indicate bearers that should be handed over to a different booster. According to another example embodiment, if the booster triggers an handover to the anchor with the purpose of indicating that bearers are handed over to a different booster, the handover request message may be enhanced with new IEs to indicate the identity of the new booster cell.

According to some of the example embodiments, the information element may also indicate that a full handover procedure was unsuccessful and thus a selective handover procedure was performed where the bearers that were not comprised in the selective handover procedure will remain associated with the source base station.

According to some of the example embodiments, the information element may provide information on a per bearer basis.

38. The method of any of example embodiments 35-37, further comprising sending (58), to the source base station, a handover complete response message, said handover complete response message comprising at least one information element on a result of the handover procedure.

According to some of the example embodiments, if the handover is unsuccessful, the information element may further comprise a cause code specifying the reason for the failure. According to some of the example embodiments, the information element may provide information

on a per bearer basis. According to some of the example embodiments, the information elements may comprise a list of non-admitted bearers.

39. The method of any of example embodiments 35-38, wherein the handover request comprises an information element indicating that the handover procedure is a selective handover procedure.
40. The method of any of example embodiments 35-39, wherein said handover request acknowledgement comprising an information element providing a result of a setup of the handover procedure.

According to some of the example embodiments, the information element may provide information on a per bearer basis.

According to some of the example embodiments, upon reception of the HANDOVER REQUEST ACKNOWLEDGE and of the E-RABs Not Admitted List, the anchor base station may decide to maintain the non-admitted bearers active and to keep on serving the user equipment with these bearers traffic.

41. The method of any of example embodiments 35-40, further comprising receiving **(60)**, from the source base station, enhanced handover request and enhanced handover complete messages for a sub-set of bearers in a subsequent selective handover procedure.

It should be appreciated that the successive selective handovers may be for the purpose of moving more bearers to/from the booster base station. If bearers need to be handed over from booster to anchor, the booster may initiate the selective handover procedures and send the Handover Request message.

42. The method of example embodiment 41, wherein the enhanced handover request and enhanced handover complete messages further comprises an E-RAB setup request and E-RAB setup response, respectively.

According to some of the example embodiments, the E-RAB setup request may be a consequence of an E-RAB setup request sent from the core network to the anchor node.

According to some of the example embodiments, the E-RAB setup request may comprise information with respect to bearers which need to be setup at the target base station.

According to some of the example embodiments, the E-RAB setup response may comprise information with respect to a result of the subsequent selective handover.

It should be appreciated that both the E-RAB setup request and E-RAB setup response may comprise information on a per bearer basis.

43. The method of any of example embodiments 41-42, wherein a subsequent handover procedure is needed based on any of the below example criteria:
- User equipment radio conditions monitored via reception of measurement reports by the user equipment-
 - Load related conditions, i.e., whether the serving anchor cell is in need to offload traffic to a booster cell.
 - Performance related conditions, i.e., whether it is more opportune for some bearers to be served by the booster cell due to the improved performance the booster node could provide (e.g. in case of bearers with predominant uplink traffic).

It shall be appreciated that in legacy handover procedures an handover execution is followed by a UE context release message aimed at removing the UE context from the source eNB. In one example embodiment, after a selective handover only the resources relative to the bearers selectively handed over are removed from the source node.

44. The method of any of example embodiments 35-43, further comprises receiving **(62)**, from the source base station, an E-RAB modify request message, said E-RAB modify request message comprising information on how to modify at least one bearer which is established at the target base station.

According to some of the example embodiments, the E-RAB modify request may be a consequence of an E-RAB modify request sent from the core network to the anchor node.

45. The method of example embodiment 44, further comprising sending **(64)**, to the source base station, an E-RAB modify response message, said E-RAB modify response message comprising information on a result of a modification to the at least one bearer.

46. The method of any of example embodiments 35-43, further comprises receiving **(66)**, from the source base station, an E-RAB release command message, said E-RAB release command message comprising instructions to release at least one bearer which is established at the target base station.

According to some of the example embodiments, the E-RAB release request may be a consequence of an E-RAB release request sent from the core network to the anchor node.

47. The method of example embodiment 46, further comprising sending **(68)**, to the source base station, an E-RAB release response message, said E-RAB release response message comprising information on a result of a release of the at least one bearer.

It should be appreciated that example embodiments 44-47 describe E-RAB management procedures between two base stations. According to some of the example embodiments, both the target and source base stations may trigger such procedures.

48. The method of any of example embodiments 35-47, further comprising receiving **(46)**, from the source base station, a RRC information report message.

According to some of the example embodiments, RRC information may comprise measurement report messages received from a user equipment.

According to some of the example embodiments, the RRC information report message may be sent as a result of a request from the target base station.

According to some of the example embodiments, the RRC INFORMATION REPORT message may also comprise other RRC messages for the purpose of sending such messages from the booster as well as from the anchor node. An example may comprise the content of the RRC Connection Reconfiguration with *MobilityControlInfo* in the RRC INFORMATION REPORT message. After receiving this message the booster node may decide to forward the information to the user equipment, therefore increasing the chances of correct reception of such information by the user equipment.

49. The method of any of example embodiments 35-48, further comprising sending **(48)**, to the source base station, a RCC CONFIGURATION REQUEST message, said RCC CONFIGURATION REQUEST message comprising a user equipment measurement configuration.

According to some of the example embodiments, the source base station may send a RCC CONFIGURATION RESPONSE to the target base station providing the target base station with the decision made with respect to the RCC CONFIGURATION REQUEST.

50. A target base station for providing a handover of at least a sub-set of bearers associated with a user equipment, the target base station comprising:

radio circuitry **(410B)** configured to receive, from a source base station, a handover request for the sub-set of bearers associated with the user equipment wherein the handover request comprises handover instructions for each bearer of the sub-set of bearers;

processing circuitry **(420B)** configured to analyse a possibility of the sub-set of bearers being admitted in the handover; and

radio circuitry **(410B)** configured to send, to the source base station, a handover request acknowledgement comprising a result of the analysing.

51. The target base station of example embodiment 50, wherein the radio circuitry **(420B)** is further configured to receive, from the source base station, a handover complete message upon a completion of the handover procedure.
52. The target base station of any of example embodiments 50-51, wherein the handover request and/or the handover complete message comprise an information element, said information element comprising any one of the following:
- An indication that the message is an *RRCConnectionReconfigurationComplete* message as defined in TS36.331.
 - User equipment specific identifications for the bearers handed over.
 - Specific identification for the handover preparation procedure to which the message corresponds to.
 - An indication as to whether the handover was completed successfully or whether it failed to complete.

By taking the X2 HANDOVER REQUEST message as an example, some of the example embodiments may comprise letting the target base station be informed that a given handover is a selective handover rather than a legacy handover (e.g., a full handover after which the user equipment connection is kept in one cell only) by introducing a new optional IE (e.g., 'selective handover') in the HANDOVER REQUEST message. This IE may take different values depending on the type of selective handover that is being requested.

For example, it may have three values, a value of "0" referring to "data radio bearers" (meaning only the data radio bearers listed in the E-RAB list are to be handed over) or value "1" referring to "signalling radio bearers" (meaning only the signalling radio bearers listed in the E-RAB list are to be handed over) or it may have the value "2" referring to "signalling and data radio bearers" (meaning signalling radio bearers as well as the data radio bearers comprised in the E-RAB list are to be handed over). The Selective Handover IE can also be comprised inside the RRC Context IE, which is also comprised in the X2: HANDOVER REQUEST message.

According to some of the example embodiments, the handover request message may contain the full list of bearers associated with the UE, each bearer being provided with an indication of whether it needs to be handed over to the target or whether it needs to continue being served by the source. In another example embodiment, the handover request message may contain two lists of bearers, one including bearers that need to be handed over to the target and one that needs to continue being served by the source.

According to some of the example embodiments, the handover request message can be sent from a booster node to either indicate bearers that need to be handed over back to

the anchor or to indicate bearers that should be handed over to a different booster. According to another example embodiment, if the booster triggers an handover to the anchor with the purpose of indicating that bearers are handed over to a different booster, the handover request message may be enhanced with new IEs to indicate the identity of the new booster cell.

According to some of the example embodiments, the information element may also indicate that a full handover procedure was unsuccessful and thus a selective handover procedure was performed where the bearers that were not comprised in the selective handover procedure will remain associated with the source base station.

According to some of the example embodiments, the information element may provide information on a per bearer basis.

53. The target base station of any of example embodiments 50-52, wherein the radio circuitry **(410B)** is further configured to send, to the source base station, a handover complete response message, said handover complete response message comprising at least one information element on a result of the handover procedure.

According to some of the example embodiments, if the handover is unsuccessful, the information element may further comprise a cause code specifying the reason for the failure. According to some of the example embodiments, the information element may provide information on a per bearer basis. According to some of the example embodiments, the information elements may comprise a list of non-admitted bearers.

54. The target base station of any of example embodiments 50-53, wherein the handover request comprises an information element indicating that the handover procedure is a selective handover procedure.

55. The target base station of any of example embodiments 50-54, wherein said handover request acknowledgement comprising an information element providing a result of a setup of the handover procedure.

According to some of the example embodiments, the information element may provide information on a per bearer basis.

According to some of the example embodiments, upon reception of the HANDOVER REQUEST ACKNOWLEDGE and of the E-RABs Not Admitted List, the anchor base station may decide to maintain the non-admitted bearers active and to keep on serving the user equipment with these bearers traffic.

56. The target base station of any of example embodiments 50-55, wherein the radio circuitry **(410B)** is further configured to receive, from the source base station, enhanced handover request and enhanced handover complete messages for a sub-set of bearers in a subsequent selective handover procedure.

It should be appreciated that the successive selective handovers may be for the purpose of moving more bearers to/from the booster base station. If bearers need to be handed over from booster to anchor, the booster may initiate the selective handover procedures and send the Handover Request message.

57. The target base station of example embodiment 56, wherein the enhanced handover request and enhanced handover complete messages further comprises an E-RAB setup request and E-RAB setup response, respectively.

According to some of the example embodiments, the E-RAB setup request may be a consequence of an E-RAB setup request sent from the core network to the anchor node.

According to some of the example embodiments, the E-RAB setup request may comprise information with respect to bearers which need to be setup at the target base station.

According to some of the example embodiments, the E-RAB setup response may comprise information with respect to a result of the subsequent selective handover.

It should be appreciated that both the E-RAB setup request and E-RAB setup response may comprise information on a per bearer basis.

58. The target base station of any of example embodiments 56-57, wherein a subsequent handover procedure is needed based on any of the below example criteria:

- User equipment radio conditions monitored via reception of measurement reports by the user equipment-
- Load related conditions, i.e., whether the serving anchor cell is in need to offload traffic to a booster cell.
- Performance related conditions, i.e., whether it is more opportune for some bearers to be served by the booster cell due to the improved performance the booster node could provide (e.g. in case of bearers with predominant uplink traffic).

It shall be appreciated that in legacy handover procedures an handover execution is followed by a UE context release message aimed at removing the UE context from the source eNB. In one example embodiment, after a selective handover only the resources relative to the bearers selectively handed over are removed from the source node.

59. The target base station of any of example embodiments 50-58, wherein the radio circuitry **(410B)** is further configured to receive, from the source base station, an E-RAB modify request message,

said E-RAB modify request message comprising information on how to modify at least one bearer which is established at the target base station.

According to some of the example embodiments, the E-RAB modify request may be a consequence of an E-RAB modify request sent from the core network to the anchor node.

60. The target base station of example embodiment 59, wherein the radio circuitry **(410B)** is further configured to send, to the source base station, an E-RAB modify response message, said E-RAB modify response message comprising information on a result of a modification to the at least one bearer.

61. The target base station of any of example embodiments 50-60, wherein the radio circuitry **(410B)** is further configured to receive, from the source base station, an E-RAB release command message, said E-RAB release command message comprising instructions to release at least one bearer which is established at the target base station.

According to some of the example embodiments, the E-RAB release request may be a consequence of an E-RAB release request sent from the core network to the anchor node.

62. The target base station of example embodiment 61, wherein the radio circuitry **(410B)** is further configured to send, to the source base station, an E-RAB release response message, said E-RAB release response message comprising information on a result of a release of the at least one bearer.

It should be appreciated that example embodiments 59-62 describe E-RAB management procedures between two base stations. According to some of the example embodiments, both the target and source base stations may trigger such procedures.

63. The target base station of any of example embodiments 50-62, wherein the radio circuitry **(410B)** is further configured to receive, from the source base station, a RRC information report message.

According to some of the example embodiments, RRC information may comprise measurement report messages received from a user equipment.

According to some of the example embodiments, the RRC information report message may be sent as a result of a request from the target base station.

According to some of the example embodiments, the RRC INFORMATION REPORT message may also comprise other RRC messages for the purpose of sending such messages from the booster as well as from the anchor node. An example may comprise the content of the RRC Connection Reconfiguration with *MobilityControlInfo* in the RRC INFORMATION REPORT message. After receiving this message the booster node may decide to forward the information to

the user equipment, therefore increasing the chances of correct reception of such information by the user equipment.

64. The target base station of any of example embodiments 50-63, wherein the radio circuitry **(410B)** is further configured to send, to the source base station, a RCC CONFIGURATION REQUEST message, said RCC CONFIGURATION REQUEST message comprising a user equipment measurement configuration.

According to some of the example embodiments, the source base station may send a RCC CONFIGURATION RESPONSE to the target base station providing the target base station with the decision made with respect to the RCC CONFIGURATION REQUEST.

SELECTIVE HANDOVER: CN ENHANCEMENTS TO SUPPORT UE MULTIPLE CONNECTIVITY

1 Technical area/Keywords

Heterogeneous networks, Het Net, Pico, Soft cell, Handover, Handoff, LTE, Rel 12

2 Overview

With the proliferation of user friendly smart phones and tablets, the usage of high data rate services such as video streaming over the mobile network is becoming commonplace, greatly increasing the amount of traffic in mobile networks. Thus, there is a great urgency in the mobile network community to ensure that the capacity of mobile networks keeps up increasing with this ever-increasing user demand. The latest systems such as Long Term Evolution (LTE), especially when coupled with interference mitigation techniques, have spectral efficiencies very close to the theoretical Shannon limit. The continuous upgrading of current networks to support the latest technologies and densifying the number of base stations per unit area are two of the most widely used approaches to meet the increasing traffic demands.

Yet another approach that is gaining high attention is to use Heterogeneous Networks where the traditional pre-planned macro base stations (known as the *macro layer*) are complemented with several low-powered base stations that may be deployed in a relatively unplanned manner. The 3rd Generation Partnership Project (3GPP) has incorporated the concept of Heterogeneous Networks as one of the core items of study in the latest enhancements of LTE, such as LTE release 11. and several low-powered base stations for realizing heterogeneous networks such as *pico* base stations, *femto* base stations (also known as home base stations or HeNBs), relays, and RRHs (remote radio heads) have been defined.

The initial discussion for LTE release 12 has already started and one of the proposed items for study is the possibility of serving a User Equipment (UE) from more than one eNB simultaneously. The current legacy handover mechanisms of LTE have to be updated in order to support this.

3 Description

3.1 Technical Background / Existing Technology

3.1.1 Overall E-UTRAN architecture

The Evolved UMTS Terrestrial Radio Access Network (E-UTRAN) consists of base stations called enhanced NodeBs (eNBs or eNodeBs), providing the E-UTRA user plane and control plane protocol terminations towards the UE. The eNBs are interconnected with each other by means of the X2 interface. The eNBs are also connected by means of the S1 interface to the EPC (Evolved Packet Core), more specifically to the MME (Mobility Management Entity) by means of the S1-MME interface and to the Serving Gateway (S-GW) by means of the S1-U interface. The S1 interface supports many-to-many relation between MMEs / S-GWs and eNBs. The E-UTRAN architecture is illustrated in Figure 1 below.

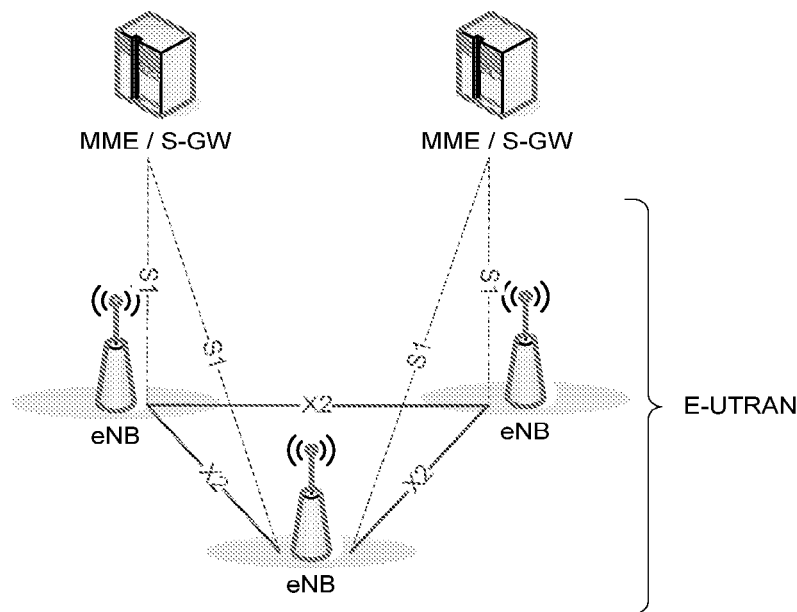


Figure 1: Overall E-UTRAN Architecture

The eNB hosts functionalities such as Radio Resource Management (RRM), radio bearer control, admission control, header compression of user plane data towards serving gateway, routing of user plane data towards the serving gateway. The MME is the control node that processes the signaling between the UE and the CN. The main functions of the MME are related to connection management and bearer management, which are handled via Non Access Stratum (NAS) protocols. The S-GW is the anchor point for UE mobility, and also comprises other functionalities such as temporary DL data buffering while the UE is being paged, packet routing and forwarding the right eNB, gathering of information for charging and lawful interception. The PDN Gateway (P-GW) is the node responsible for UE IP address allocation, as well as Quality of Service (QoS) enforcement (this is explained further in later sections). Figure 2 gives a summary of the functionalities of the different nodes, and the reader is referred to 3GPP TS 36.300 and the references therein for the details of the functionalities of the different nodes. In Figure 2, the yellow boxes depict the logical nodes, white boxes depict the functional entities of the control plane and blue boxes depict the radio protocol layers.

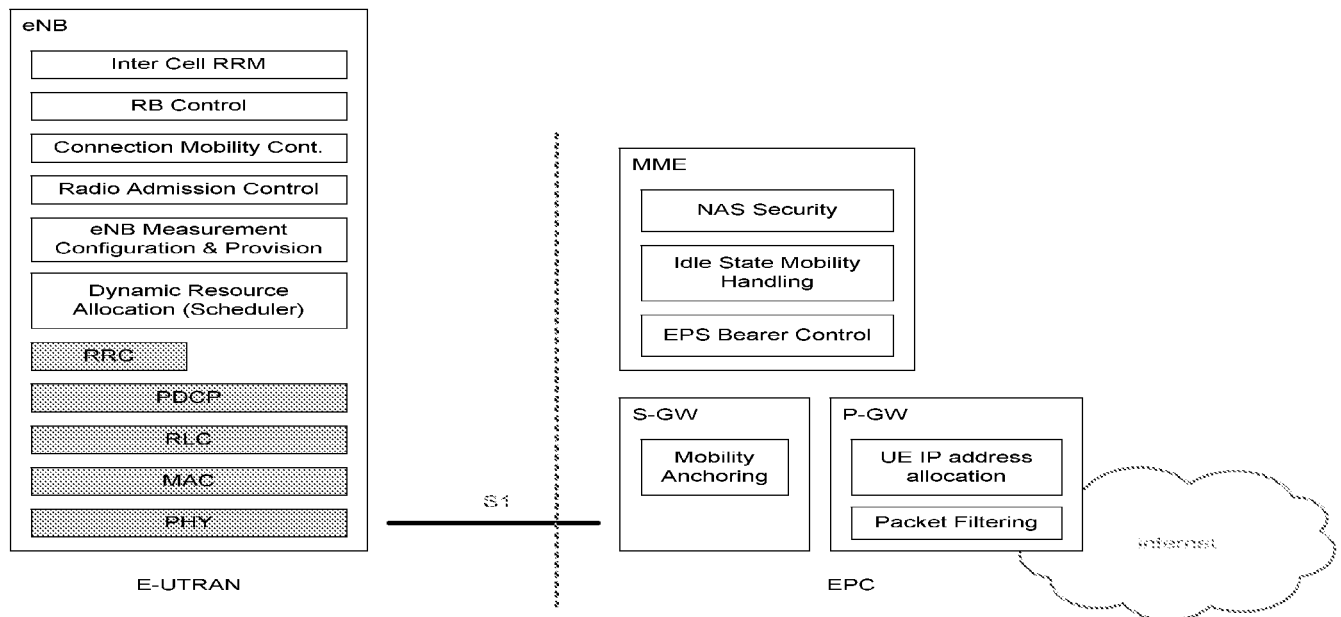


Figure 2: Functional Split between E-UTRAN and EPC

3.1.2 Radio Protocol architecture

The radio protocol architecture of E-UTRAN is divided into the user plane and the control plane.

3.1.2.1 User plane

Figure 3 shows the protocol stack for the user-plane. The user plane protocol stack is comprised of the Packet Data Convergence Protocol (PDCP), Radio Link Control (RLC), and Medium Access Control (MAC), which are terminated at the eNB. The PDCP manages IP packets in the user plane and it performs functionalities such as header compression, security, and re-ordering and retransmission during handover. The RLC layer is mainly responsible for segmentation (and corresponding assembly) of PDCP packets, in order that they fit the size that is actually to be transmitted over the air interface. RLC can operate either in unacknowledged mode or acknowledged mode, where the latter supports retransmissions. The MAC layer performs multiplexing of data from different radio bearers, and it is the one that informs the RLC about the size of the packets to provide, which is decided based on the required QoS of each radio bearer and the current capacity available to the UE.

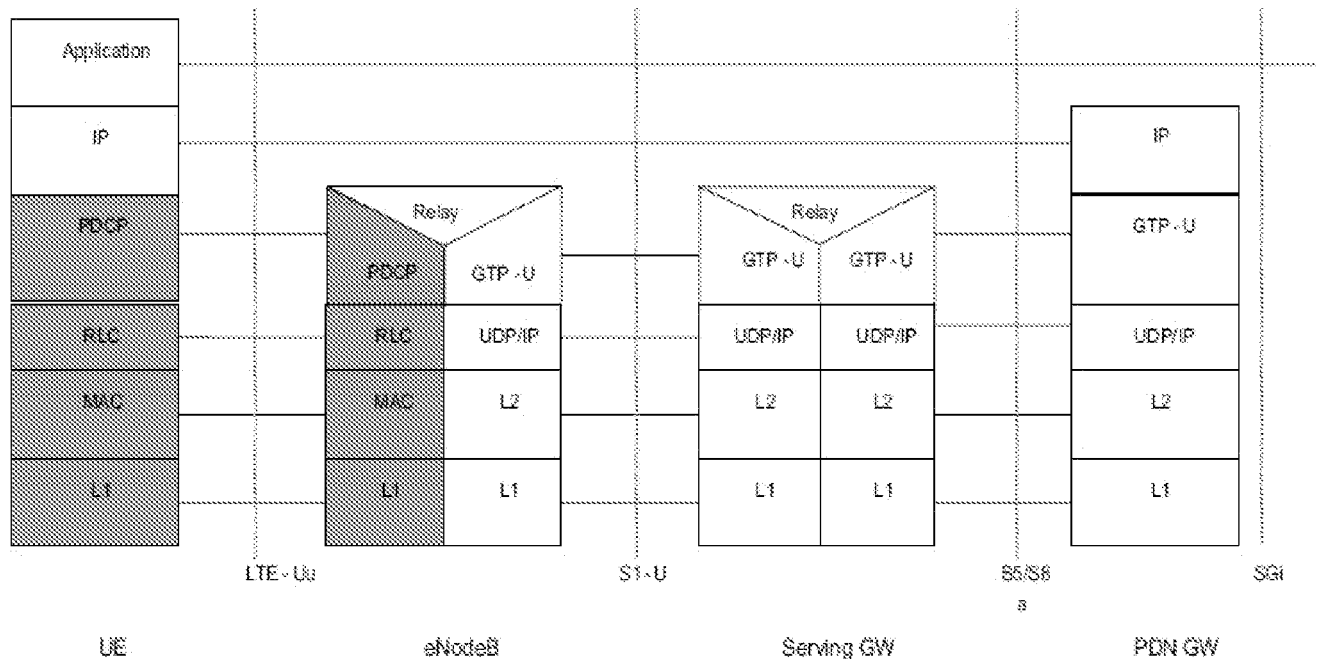


Figure 3: User plane protocol stack

3.1.2.2 Control plane

Figure 4 shows the control plane protocol stack. The layers below the Radio Resource Control (RRC) layer perform the same functionality as in the user plane except that there is no header compression in the control plane. The main functions of the RRC are the broadcasting of system information, RRC connection control (establishment, modification, and release of RRC connection, establishment of signalling radio bearers (SRB) and data radio bearers (DRBs), handover, configuration of lower protocol layers, radio link failure recovery, etc...), and measurement configuration and reporting. The details of the RRC protocol functionalities and procedures can be found in 3GPP TS 36.331.

A UE is uniquely identified over the S1 interface within an eNB with the eNB UE S1AP ID. When an MME receives an eNB UE S1AP ID it stores it for the duration of the UE-associated logical S1-connection for this UE. Once known to an MME this IE is comprised in all UE associated S1-AP signalling. The eNB UE S1AP ID is unique within the eNB, and UEs are assigned new S1AP ID after a handover by the target eNB.

From the MME side, a UE is uniquely identified using the MME UE S1AP ID. When an eNB receives MME UE S1AP ID it stores it for the duration of the UE-associated logical S1 connection for this UE. Once known to an eNB this IE is comprised in all UE associated S1-AP signalling. The MME UE S1AP ID is unique within the MME, and it is changed if the UE's MME changes (for example, handover between two eNBs connected to different MMEs).

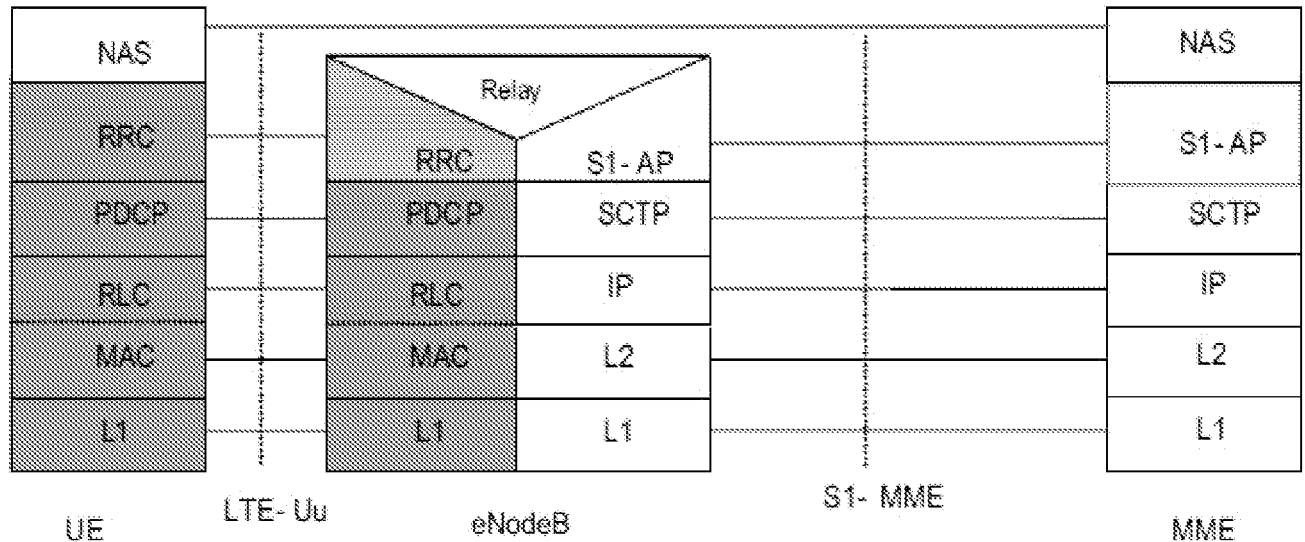


Figure 4: Control plane protocol stack

3.1.2.3 Flow of user plane and control plane data

The flow of user plane and control plane data is illustrated in Figure 5. There is only one MAC entity per UE (unless the UE supports multiple carriers as in the case of carrier aggregation) and under this MAC entity, several Hybrid ARQ (HARQ) processes might be running simultaneously for rapid retransmissions. There is a separate RLC entity for each radio bearer and if the radio bearer is configured to use PDCP, there is also one separate PDCP entity for that bearer. A bearer is configured to use PDCP only if it is dedicated to a UE (i.e. multicast and broadcast data do not utilize PDCP both in the control and user plane and the PDCP is used only for dedicated control message in the control plane and for dedicated UL/DL data in the user plane).

At the transmitting side each layer receives a Service Data Unit (SDU) from a higher layer, and sends a Protocol Data Unit (PDU) to the lower layer. For example, PDCP PDUs are sent towards the RLC, and they are RLC SDUs from RLC point of view, which in turn sends RLC PDUs towards the MAC, which are MAC SDUs from the MAC point of view. At the receiving end, the process is reversed, i.e. each layer passing SDUs to the layer above it, where they are perceived as PDUs.

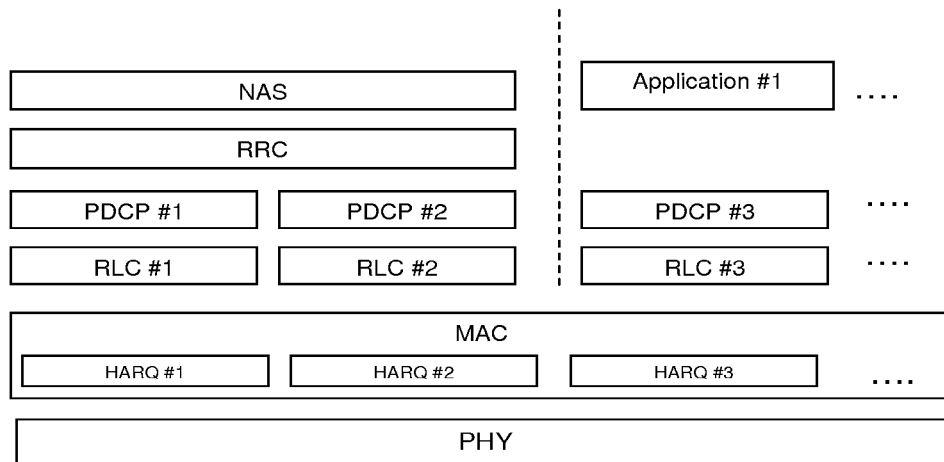


Figure 5: User plane and control plane data flow.

3.1.3 QoS

A UE can have multiple applications running at the same time, each having different QoS requirements (for example, VoIP, browsing, file download ...). In order to support these different requirements, different bearers are set up, each being associated with a QoS. An EPS bearer/E-RAB (Radio Access Bearer) is the level of granularity for bearer level QoS control in the EPC/E-UTRAN. That is, Service Data Flows (SDF) mapped to the same EPS bearer receive the same bearer level packet forwarding treatment (e.g. scheduling policy, queue management policy, rate shaping policy, RLC configuration, etc.) .

One EPS bearer/E-RAB is established when the UE connects to a PDN, and that remains established throughout the lifetime of the PDN connection to provide the UE with always-on IP connectivity to that PDN. That bearer is referred to as the *default* bearer. Any additional EPS bearer/E-RAB that is established to the same PDN is referred to as a *dedicated* bearer. The initial bearer level QoS parameter values of the default bearer are assigned by the network, based on subscription data. The decision to establish or modify a dedicated bearer can only be taken by the EPC, and the bearer level QoS parameter values are always assigned by the EPC.

An EPS bearer/E-RAB is referred to as a GBR bearer if dedicated network resources related to a Guaranteed Bit Rate (GBR) value that is associated with the EPS bearer/E-RAB are permanently allocated (e.g. by an admission control function in the eNB) at bearer establishment/modification. Otherwise, an EPS bearer/E-RAB is referred to as a Non-GBR bearer. A dedicated bearer can either be a GBR or a Non-GBR bearer while a default bearer shall be a Non-GBR bearer.

The EPS bearer service architecture is shown in Figure 6. The packets of an EPS bearer are transported over a radio bearer between the UE and eNB. An S1 bearer transports the packets of an EPS bearer between the eNB and S-GW. An E-RAB is actually a concatenation of these two bearers (i.e. radio bearer and S1 bearer), and the two bearers are mapped on a one to one fashion. An S5/S8 bearer transports the packets of the EPS bearer between the S-GW and P-GW, and completes the EPS bearer. Here also there is a one to one mapping between the E-RAB and S5/S8 bearer.

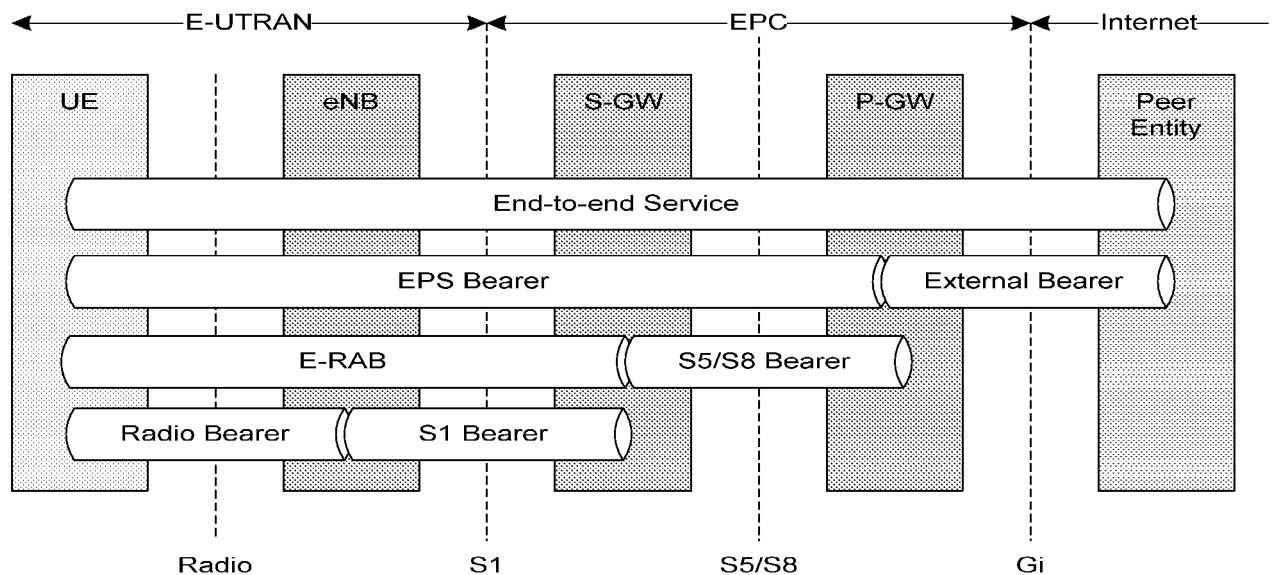


Figure 6: EPS Bearer Service Architecture

The bearer level (i.e. per bearer or per bearer aggregate) QoS parameters are QCI, ARP, GBR, and AMBR. Each EPS bearer/E-RAB (GBR and Non-GBR) is associated with the following bearer level QoS parameters:

- **QoS Class Identifier (QCI):** scalar that is used as a reference to access node-specific parameters that control bearer level packet forwarding treatment (e.g. scheduling weights, admission thresholds, queue management thresholds, link layer protocol configuration, etc.), and that have been pre-configured by the operator owning the eNodeB. Nine QCI values are standardized the detailed requirements of these classes can be found in 3GPP TS 23.203.
- **Allocation and Retention Priority (ARP):** the primary purpose of ARP is to decide whether a bearer establishment / modification request can be accepted or needs to be rejected in case of resource limitations. In addition, the ARP can be used by the eNodeB to decide which bearer(s) to drop during exceptional resource limitations (e.g. at handover).

Each GBR bearer is additionally associated with the following bearer level QoS parameters:

- **Guaranteed Bit Rate (GBR):** the bit rate that can be expected to be provided by a GBR bearer
- **Maximum Bit Rate (MBR):** the maximum bit rate that can be expected to be provided by a GBR bearer. MBR can be greater or equal to the GBR.

Each APN access, by a UE, is associated with a per-APN Aggregate Maximum Bit Rate (APN-AMBR). The APN-AMBR sets the limit on the aggregate bit rate that can be expected to be provided across all Non-GBR bearers and across all PDN connections of the same APN.

Each UE in state EMM-REGISTERED is associated with the bearer aggregate level QoS parameter known as per UE Aggregate Maximum Bit Rate (UE-AMBR). The UE-AMBR

limits the aggregate bit rate that can be expected to be provided across all Non-GBR bearers of a UE.

3.1.4 Heterogeneous Networks and Soft/Shared Cells

The use of a so called *heterogeneous deployment* or *heterogeneous network*, as illustrated in Figure 7, consisting of network transmission nodes with different transmit power operating and with overlapping coverage areas, is considered to be an interesting future deployment strategy for cellular networks. In such a deployment, the low-power nodes (“pico nodes”) are typically assumed to offer high data rates (Mbit/s), as well as provide high capacity (users/m² or Mbit/s/m²), in the local areas where this is needed/desired, while the high-power nodes (“macro nodes”) are assumed to provide full-area coverage. In practice, the macro nodes may correspond to currently deployed macro cells while the pico nodes are later deployed nodes, extending the capacity and/or achievable data rates within the macro-cell coverage area where needed.

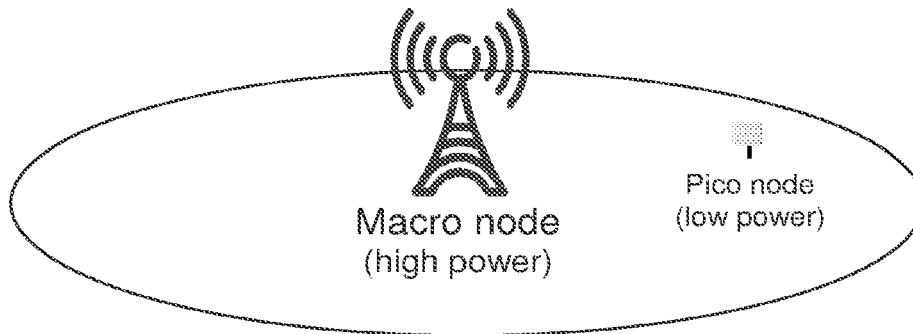


Figure 7: Heterogeneous deployment with a higher-power macro node and a lower-power pico node. In a typical case, there may be multiple pico nodes within the coverage area of a macro node.

A pico node of a heterogeneous deployment may correspond to a cell of its own (a “pico cell”), see Figure 8. This means that, in addition to downlink and uplink data transmission/reception, the pico node also transmits the full set of common signals/channels associated with a cell. In the LTE context this comprises:

- The *Primary and Secondary Synchronization Signals* (PSS and SSS) corresponding to the *Physical Cell Identity* of the pico cell.
- The *Cell-specific reference signals* (CRS), also corresponding to the Physical Cell Identity of the cell. The CRS can e.g. be used for downlink channel estimation to enable coherent demodulation of downlink transmissions.
- The *Broadcast channel* (BCH), with corresponding pico-cell system information¹

As the pico node transmits the common signals/channels, the corresponding pico cell can be detected and selected (connected to) by a terminal (UE, user equipment).

¹ Additional system information is transmitted on the PDSCH physical channel

If the pico node corresponds to a cell of its own, also so-called *L1/L2 control signaling* on the PDCCH (as well as PCFICH and PHICH) are transmitted from the pico node to connected terminals, in addition to downlink data transmission on the PDSCH. The L1/L2 control signaling e.g. provides downlink and uplink scheduling information and Hybrid-ARQ-related information to terminals within the cell. This is shown in Figure 8.

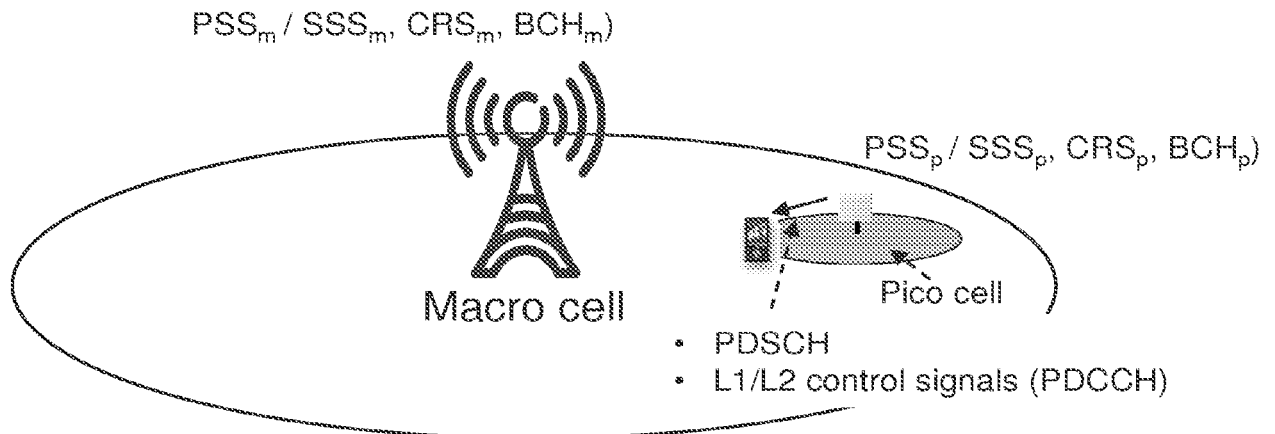


Figure 8: Heterogeneous deployment where the pico node corresponds to a cell of its own (a "pico cell"). The indices "p" and "m" indicate common signals/channels for the pico and macro cell respectively.

Alternatively, a pico node within a heterogeneous deployment may not correspond to a cell of its own but may just provide a data-rate and capacity "extension" of the overlaid macro cell, see e.g. P32215. This is sometimes known as "shared cell" or "soft cell". In this case at least the CRS, PBCH, PSS and SSS are transmitted from the macro node. The PDSCH can be transmitted from the pico node. To allow for demodulation and detection of the PDSCH, despite the fact that no CRS is transmitted from the pico node, DM-RS should be transmitted from the pico node together with the PDSCH. The UE-specific reference signals can then be used by the terminal for PDSCH demodulation/detection. This is shown in Figure 9.

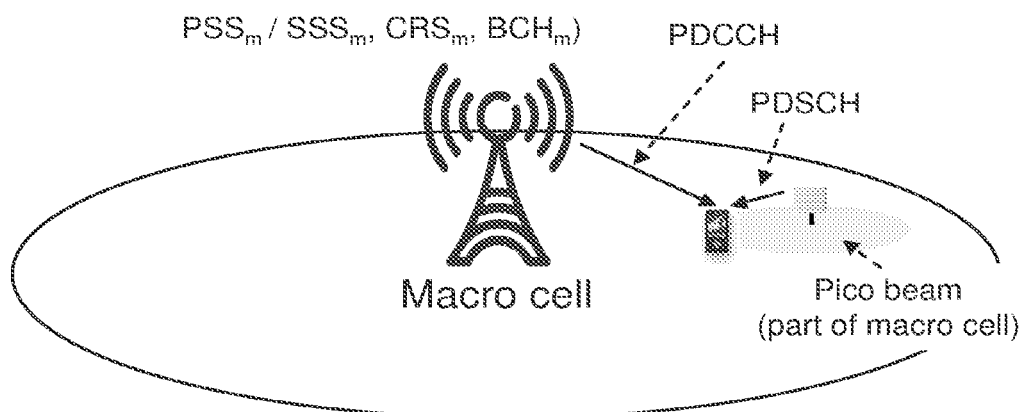


Figure 9: Heterogeneous deployment where the pico node does not correspond to a cell of its own

Transmitting data from a pico node not transmitting CRS as described above requires DM-RS support in the terminal (“non-legacy terminal”). In LTE, DM-RS-based PDSCH reception is supported in Rel-10 and for FDD while for the L1/L2 control signalling, DM-RS-based reception is planned for Rel-11. For terminals not supporting DM-RS-based reception (“legacy terminals”) one possibility in a shared cell setting is to exploit SFN²-type of transmission. In essence *identical* copies of the signals and channels necessary for a legacy terminal are transmitted *simultaneously* from the macro and pico nodes. From a terminal perspective this will look as a single transmission. Such an operation, which is illustrated in Figure 10, will only provide an SINR gain, which can be translated into a higher data rate but not a capacity improvement, as transmission resources cannot be reused across sites within the same cell.

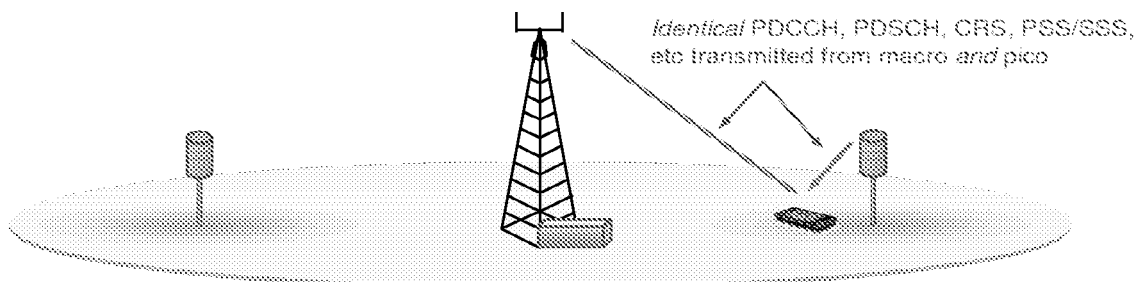


Figure 10: SFN operation with *identical* transmission from macro and pico to a terminal.

If we can assume that the macros are able to provide coverage and the picos are there only for capacity enhancements (i.e. no coverage holes), another alternative architecture is where the UE maintains the macro connectivity all the time (called the “anchor” link), and adds the pico connectivity when it is in the coverage area of the pico (called the “booster” link). When both connections are active, the anchor link can be used either for control signalling while the booster link is used for data. However, it will still be possible to send data also via the anchor link. This is illustrated in Figure 11. Note that in this case, as in the previous cases, the system information is shown to be sent only from the macro, but it is still possible to send it also from the picos.

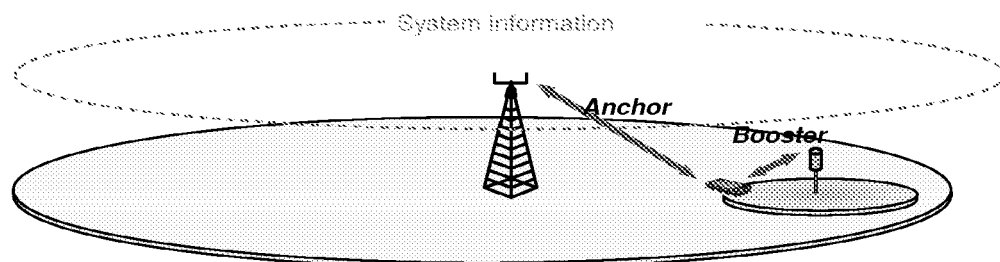


Figure 11: Soft cell operation with the UE having multiple connections with both the anchor and booster.

² Single Frequency Network

3.1.4.1 Protocol architecture for Soft Cells

In order to support multiple connectivity, several architectural options are possible both for the control and user plane. For the user plane, we can have a centralized approach where the PDCP (or even the RLC) is terminated at the anchor only and the booster terminates at the RLC (or even the MAC) level. A decentralized approach will be to have the booster to terminate at the PDCP level. Similar approach can be taken in the control plane (i.e. distributed or centralized PDCP/RLC,) but on top of that we have the additional dimension of centralizing or distributing the RRC. Figure 12 shows an example control and user plane architectures, where the user plane is employing distributed PDCP, while the control plane is centralized at the PDCP level at the anchor. Note that in the figure, user plane aggregation (i.e. the possibility to split the packets belonging to one application data flow over the anchor and booster links) can be realized by using a higher layer aggregation protocol like multi-path TCP (MPTCP).

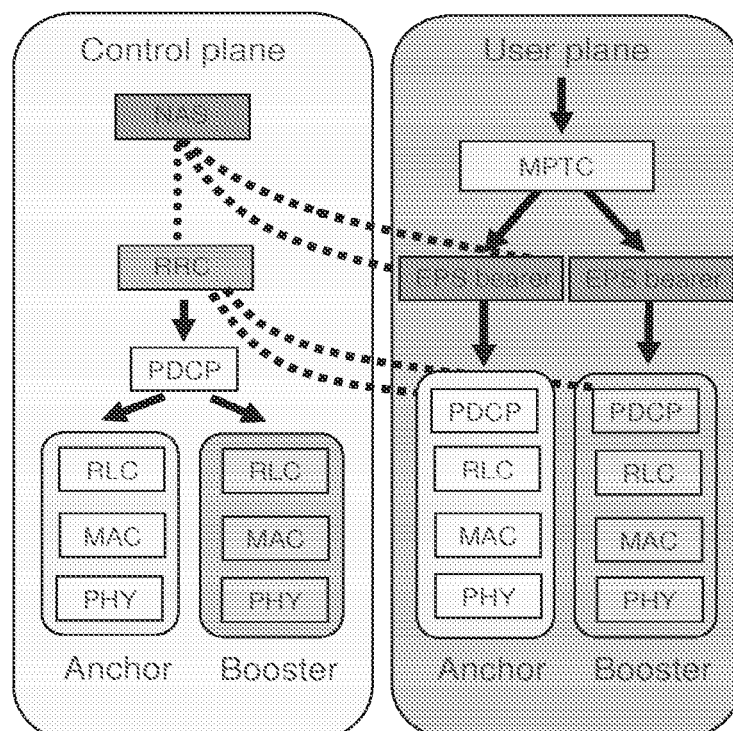


Figure 12: Example protocol architecture for multiple connectivity.

3.1.5 UE measurements

UEs can be configured to report measurements, mainly for the sake of supporting mobility. As specified in 3GPP TS 36.331, the E-UTRAN provides the measurement configuration applicable for a UE in RRC_CONNECTED by means of dedicated signalling, i.e. using the *RRCConnectionReconfiguration* message. The following measurement configurations can be signalled to the UE:

1. **Measurement objects:** These define on what the UE should perform the measurements – such as a carrier frequency. The measurement object may also comprise a list of cells to be considered (white-list or black-list) as well as associated parameters, e.g. frequency- or cell-specific offsets.

2. **Reporting configurations:** These consist of the periodic or event-triggered criteria which cause the UE to send a measurement report, as well as the details of what information the UE is expected to report (e.g. the quantities, such as Received Signal Code Power (RSCP) for UMTS or Reference Signal Received Power (RSRP) for LTE, and the number of cells).
3. **Measurement identities:** These identify a measurement and define the applicable measurement object and reporting configuration. Each measurement identity links one measurement object with one reporting configuration. By configuring multiple measurement identities it is possible to link more than one measurement object to the same reporting configuration, as well as to link more than one reporting configuration to the same measurement object. The measurement identity is used as a reference number in the measurement report.
4. **Quantity configurations:** The quantity configuration defines the filtering to be used on each measurement. One quantity configuration is configured per RAT type, and one filter can be configured per measurement quantity.
5. **Measurement gaps:** Measurement gaps define time periods when no uplink or downlink transmissions will be scheduled, so that the UE may perform the measurements (e.g. inter-frequency measurements where the UE has only one Tx/Rx unit and supports only one frequency at a time). The measurement gaps are common for all gap-assisted measurements

The E-UTRAN configures only a single measurement object for a given frequency, but more than one measurement identity may use the same measurement object. The identifiers used for the measurement object and reporting configuration are unique across all measurement types. It is possible to configure the quantity which triggers the report (RSCP or RSRP) for each reporting configuration.

In LTE, example measurements metric used are the Reference Signal Received Power (RSRP) and Reference Signal Received Quality (RSRQ). RSRP is a cell specific measure of signal strength and it is mainly used for ranking different cells for handover and cell reselection purposes, and it is calculated as the linear average of the power of the Resource Elements (REs) which carry cell-specific Reference Signals (RSs). The RSRQ, on the other hand, also takes the interference into consideration by taking the total received wideband power into account as well.

One of the measurement configuration parameters that UEs receive from their serving eNBs is the *S-measure*, which tells the UE when to start measuring neighbouring cells. If the measured RSRP of the serving cell falls below the S-measure, indicating the signal of the serving cell is not that strong anymore, the UE starts measuring the signal strength of RSs from the neighbouring cells. The S-measure is an optional parameter and different S-measure values can be specified for initiating intra-frequency, inter-frequency and inter-RAT measurements.

Once the UE is enabled for measuring, it can report any of the following:

- The serving cell
- Listed cells (i.e. cells indicated as part of the measurement object);
- Detected cells on a listed frequency (i.e. cells which are not listed cells but are detected by the UE).

There are several measurement configuration parameters that specify the triggering of measurement reports from the UE. The following event-triggered criteria are specified for intra-RAT measurement reporting in LTE:

- **Event A1:** Primary serving cell (PCell) becomes better than absolute threshold.
- **Event A2:** PCell becomes worse than absolute threshold.
- **Event A3:** Neighbour cell becomes better than an offset relative to the PCell.
- **Event A4:** Neighbour cell becomes better than absolute threshold.
- **Event A5:** PCell becomes worse than one absolute threshold and neighbour cell becomes better than another absolute threshold.
- **Event A6:** Neighbour cell becomes better than an offset relative to a secondary cell (SCell)

For inter-RAT mobility, the following event-triggered reporting criteria are specified:

- **Event B1:** Neighbour cell becomes better than absolute threshold.
- **Event B2:** Serving cell becomes worse than one absolute threshold and neighbour cell becomes better than another absolute threshold.

An example measurement report triggering event related to handover is A3, and its usage is illustrated in Figure 13. The triggering conditions for event A3 can be formulated as:

$$N > S + HOM \quad (1)$$

where N and S are the signal strengths of the neighbour and serving cells, respectively, and HOM is the handover margin. HOM is the difference between the radio quality of the serving cell and the radio quality needed before attempting a handover. The radio quality is measured either using RSRP or RSRQ (see 36.133 for further explanation).

The UE triggers the intra-frequency handover procedure by sending event A3 report to the eNB. This event occurs when the UE measures that the target cell is better than the serving cell with a margin “HOM”. The UE is configured over RRC when entering a cell and the HOM is calculated from the following configurable parameters:

$$HOM = Of_s + Ocs + Off - Of_n - Ocn + Hys$$

Where:

Of_s is the frequency specific offset of the serving cell

Ocs is the cell specific offset (CIO) of the serving cell

Off is the a3-Offset

Of_n is the frequency specific offset of the neighbor cell

Ocn is the CIO of the neighbor cell

Hys is the hysteresis

If the condition in (1) is satisfied and it remains valid for a certain duration known as Time To Trigger (TTT), the UE sends a measurement report to the serving eNB (in Figure 3, event A3 is satisfied at point A and measurement report is sent at point B in time). When the serving eNB gets the measurement report, it can initiate a handover towards the neighbour.

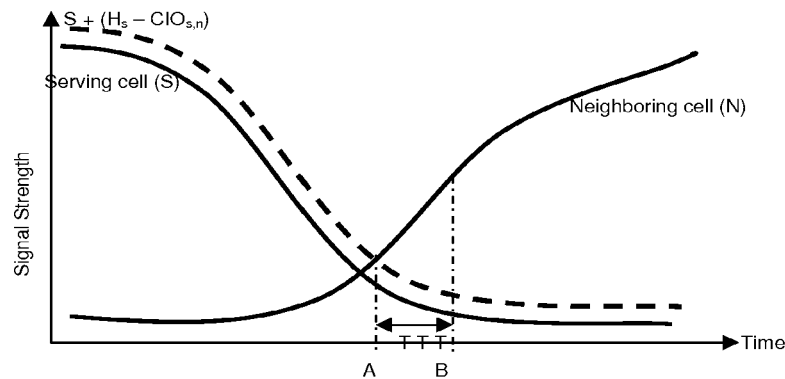


Figure 13: Handover triggering in LTE

In addition to event-triggered reporting, the UE may be configured to perform periodic measurement reporting. In this case, the same parameters may be configured as for event-triggered reporting, except that the UE starts reporting immediately rather than only after the occurrence of an event.

3.1.6 Handover

Handover is one of the important aspects of any mobile communication system, where the system tries to assure service continuity of the User Equipment (UE) by transferring the connection from one cell to another depending on several factors such as signal strength, load conditions, service requirements, etc. The provision of efficient/effective handovers (minimum number of unnecessary handovers, minimum number of handover failures, minimum handover delay, etc.), would affect not only the Quality of Service (QoS) of the end user but also the overall mobile network capacity and performance.

In LTE, UE-assisted, network controlled handover is utilized (3GPP TS 36.300). The handover is based on UE reports, and the UE is moved, if required and possible, to the most appropriate cell that will assure service continuity and quality.

Handover is performed via the X2 connection, whenever available, and if not, using S1 (i.e. involving the Core Network (CN)). The X2 Handover process is shown in Figure 14. The handover procedure can be sub divided into three stages of *preparation (initiation)*, *execution* and *completion*.

The main steps of the handover process are:

1. The source eNB configures the UE measurement procedures. This can be done either when the UE first connects to an eNB (comprised in the HO command as described later) or later one by sending measurement reconfigurations. The measurement configurations are sent to the UE by using the *measConfig* Information Element (IE) that is comprised in the *RRCConnectionReconfiguration* message.
2. The UE is triggered to send a measurement report by the measurement rules set as described in the previous section
3. Based on the received measurement report and other RRM information, the source eNB makes a decision to hand over the UE to the target.

4. The source eNB issues a HANDOVER REQUEST message to the target eNB passing necessary information to prepare the HO at the target side. The source eNB must indicate the cause of the HO in this message, which can be, e.g.,
 - a. Handover Desirable for Radio Reasons,
 - b. Resource Optimization Handover,
 - c. Reduce Load in Serving Cell
5. Admission Control may be performed by the target eNB.
6. The target eNB prepares HO with L1/L2 and sends the HANDOVER REQUEST ACKNOWLEDGE to the source eNB. The HANDOVER REQUEST ACKNOWLEDGE message comprises an Information Element (IE) called "Target eNB to Source eNB Transparent Container". This IE is basically comprises the handover command message (*RRConnectionReconfiguration* that comprises the *mobilityControlInfo* IE) that is sent to the UE in the next step.

NOTE: As soon as the source eNB receives the HANDOVER REQUEST ACKNOWLEDGE, or as soon as the transmission of the handover command is initiated in the downlink, user plane data forwarding may be initiated.
7. The source eNB sends the handover command (i.e. *RRConnectionReconfiguration* message comprising the *mobilityControlInfo*) towards the UE on behalf of the target eNB.
8. The source eNB sends the SN (Sequence Number) STATUS TRANSFER message to the target eNB, which comprises the ID of the impacted E-RABs and PDCP SNs for UL and DL data transfer.
9. After receiving the *RRConnectionReconfiguration* message comprising the *mobilityControlInfo*, UE performs synchronisation to target eNB and accesses the target cell via RACH. If the received *RRConnectionReconfiguration* comprised dedicated RACH information, the dedicated preamble comprised in there is used for the RACH access. Otherwise, a contention based approach is taken. The UE also configures the lower layer protocol stacks based on the received configuration information.
10. The target eNB responds with UL allocation and timing advance.
11. When the UE has successfully accessed the target cell, the UE sends the *RRConnectionReconfigurationComplete* message to the target to confirm that the handover succeeded. Optionally, the UE can indicate to the target if it has information regarding earlier Radio Link Failure (RLF) or other logged measurements that could be used for optimization purposes. After the confirmation is received, the target eNB can begin sending data to the UE and the UE can send data to the target based on the scheduling grants it is receiving. However, the data from the CN is still routed to the source eNB.
12. The target eNB sends a PATH SWITCH REQUEST message to MME to inform that the UE has changed the cell. Table 1 shows the contents of the PATH SWITCH REQUEST message. If not all the UE bearers are comprised in the E-RAB To Be Switched in Downlink List, the MME considers the non-comprised E-RABs as implicitly released by the eNB (TS 36.413). That is, normal operation will be for the target eNB to list only those bearers that it has admitted during admission control

and that it has communicated earlier to the source via the HANDOVER REQUEST ACKNOWLEDGE message. The MME releases the non-accepted dedicated bearers by triggering bearer release procedures (3GPP TS 23.401).

Table 1: PATH SWITCH REQUEST message.

IE/Group Name	Presence	Range	IE type and reference	Semantics description	Criticality	Assigned Criticality
Message Type	M		9.2.1.1		YES	reject
eNB UE S1AP ID	M		9.2.3.4		YES	reject
E-RAB To Be Switched in Downlink List		1			YES	reject
>E-RABs Switched in Downlink Item IEs		1 to <maxnoof E-RABs>			EACH	reject
>>E-RAB ID	M		9.2.1.2		-	
>>Transport layer address	M		9.2.2.1		-	
>>GTP-TEID	M		9.2.2.2	To deliver DL PDUs	-	
Source MME UE S1AP ID	M		9.2.3.3		YES	reject
E-UTRAN CGI	M		9.2.1.38		YES	ignore
TAI	M		9.2.3.16		YES	ignore
UE Security Capabilities	M		9.2.1.40		YES	ignore
CSG Id	O		9.2.1.62		YES	ignore
Cell Access Mode	O		9.2.1.74		YES	ignore
Source MME GUMMEI	O		9.2.3.9		YES	ignore

13. The MME sends a MODIFY BEARER REQUEST message to the Serving Gateway. The MME comprises the bearers to be switched to the new target in the "Bearer contexts to be modified" field and the ones not received in the PATH SWITCH REQUEST message in the "Bearer context to be removed" field of the MODIFY BEARER REQUEST message (3GPP TS 29.274).
14. The Serving Gateway switches the downlink data path to the target side. That is, it starts sending downlink packets to the target eNodeB using the newly received address and TEIDs (3GPP TS 23.401). The Serving gateway sends one or more "end marker" packets on the old path to the source eNB and then can release any U-plane/TNL resources towards the source eNB.
15. The Serving Gateway sends a MODIFY BEARER RESPONSE message to MME.
16. The MME confirms the PATH SWITCH REQUEST message with the PATH SWITCH REQUEST ACKNOWLEDGE message. Table 2 shows the contents of this message.

Table 2: PATH SWITCH REQUEST ACKNOWLEDGE message.

IE/Group Name	Presence	Range	IE type and reference	Semantics description	Criticality	Assigned Criticality
Message Type	M		9.2.1.1		YES	reject
MME UE S1AP ID	M		9.2.3.3		YES	ignore
eNB UE S1AP ID	M		9.2.3.4		YES	ignore
UE Aggregate Maximum Bit Rate	O		9.2.1.20		YES	ignore
E-RAB To Be Switched in Uplink List		0..1			YES	ignore
>E-RABs Switched in Uplink Item IEs		1 to <maxnoof E-RABs>			EACH	ignore
>>E-RAB ID	M		9.2.1.2		-	
>>Transport Layer Address	M		9.2.2.1		-	
>>GTP-TEID	M		9.2.2.2		-	
E-RAB To Be Released List	O		E-RAB List 9.2.1.36	a value for E-RAB ID shall only be present once in E-RAB To Be Switched in Uplink List IE + E-RAB to Be Released List IE	YES	ignore
Security Context	M		9.2.1.26	One pair of {NCC, NH} is provided	YES	reject
Criticality Diagnostics	O		9.2.1.21		YES	ignore
MME UE S1AP ID 2	O		9.2.3.3	This IE indicates the MME UE S1AP ID assigned by the MME	YES	ignore

17. By sending the UE CONTEXT RELEASE message, the target eNB informs success of HO to source eNB and triggers the release of resources by the source eNB.
18. Upon reception of the UE CONTEXT RELEASE message, the source eNB can release radio and C-plane related resources associated to the UE context. Any ongoing data forwarding may continue.

3.2 Overview of the example embodiments

LTE currently supports only one to one connections between UEs and eNBs. As such, when a handover is initiated, the target is asked to admit all the bearers of the UE. If for some reason, such as overload situation, that some of the bearers can't be admitted at the target, the source can either cancel the handover (and possibly try another candidate target) or accept it and handover the UE to the target, which will result in the dropping of the non-admitted bearers. This can have severe consequences on the overall experience of the user.

Current specifications do not allow the setup of bearers in parallel and in multiple eNBs for the same UE, which is needed for enabling multiple connectivity. This would allow an optimal distribution of bearers depending on their QoS and UL/DL requirements.

Some of the example embodiments addresses the required changed in the communication between the eNBs and the CN to enable the possibility to connect a UE to multiple eNBs.

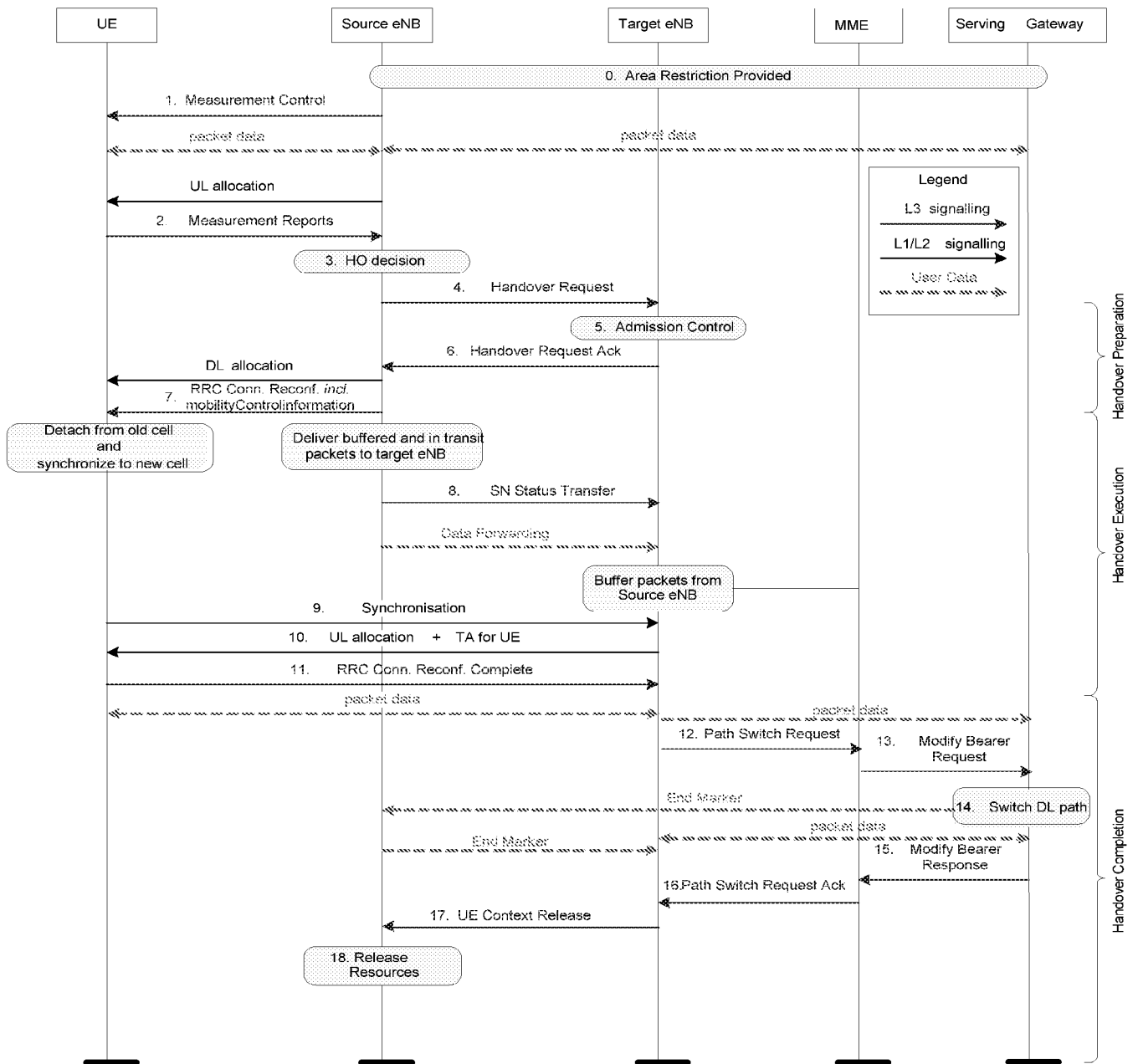


Figure 14: X2 Handover in LTE