LTE Release 9 Technology Introduction

White paper

The LTE technology as specified within 3GPP Release 8 was first commercially deployed by end 2009. Since then the number of operators implementing the technology is strongly increasing around the globe. LTE has become the fastest developing mobile system technology. The same way GSM and WCDMA have been enhanced with additional features over time, LTE is continuously worked on. Initial enhancements have been included in 3GPP Release 9 and are described in this white paper.

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1 Introduction

Initiated in 2004, the Long Term Evolution (LTE) project in 3GPP standardization focused on enhancing the Universal Terrestrial Radio Access (UTRA) and optimizing 3GPP's radio access architecture. In 2007, LTE progressed from the feasibility study stage to the first issue of approved technical specifications. End 2008 the specifications were sufficiently stable for commercial implementation and the first commercial LTE network was launched in Sweden and Norway in December 2009. 35 commercial networks were launched by end October 2011.

From experience on GSM and UMTS it can be seen that the initial specification release after creation of a new technology is usually a minor one. This means this first follow-up release includes leftovers, that were not completed in the initial release or some smaller features are added. As an example UMTS Release 4, the first release after creation of the UMTS technology in early 2000, included the additional UMTS TDD mode – not finalized in Release 99 – and just small optimizations of the FDD mode. More significant enhancements like the HSDPA feature took another release to be included in the specifications. The same holds true for LTE Release 9. The Release includes a set of features that either were not completed in release 8 or which provide some smaller optimizations or improvements. These are namely:

- Multimedia Broadcast Multicast Services (MBMS) for LTE,
- LTE MIMO: dual-layer beamforming,
- LTE positioning
- PWS (Public Warning System)
- RF requirements for multi-carrier and multi-RAT base stations,
- Home eNodeB specification (femto-cell),
- Self–Organizing Networks (SON).

This application note describes each feature in detail.

2 evolved MBMS (eMBMS)

2.1 History of MBMS

As the term evolved implies, Multimedia Broadcast Multicast Services (MBMS), is not fundamentally new to 3GPP and not defined as a LTE-only feature. In fact MBMS has first time been specified with 3GPP Release 6. It has than continuously been enhanced in the following versions of the specification. Initially defined for UTRAN/WCDMA (3G) it is also supported by GERAN/GSM (2G).

The goal with MBMS is to provide network operators with the possibility to broadcast over their cellular network. Some advantages are considered over traditional mobile broadcast technologies, such as DVB-H, DMB-H or former MediaFLO. These are:

- The same infrastructure is used
- No need for additional spectrum
- Interaction with user is possible due to available uplink

An important aspect while defining MBMS was to keep the impact to the existing network architecture as minimal as possible. Therefore only one new network element was introduced, where for the existing nodes only new tasks have been added. The MBMS network architecture and the task of the different network elements is shown in Figure 1.

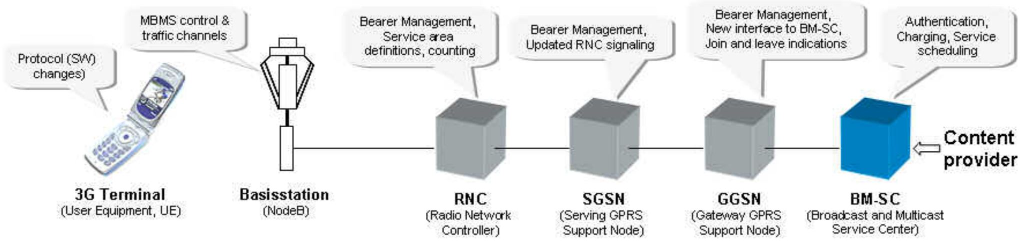


Figure 1: **MBMS network architecture for 3G networks and related tasks**

At the terminal side an enhancement to the existing channel architecture was required to enable the delivery of broadcast and multicast services. Three new logical channels where introduced, providing information on the configuration of active MBMS services, scheduling information and the broadcast data itself. Only one new physical channel is required to inform terminals about the availability of MBMS services in that particular radio cell.

The enhanced channel model is shown in Figure 2 illustrating minimal impact on terminal as well as on network side.

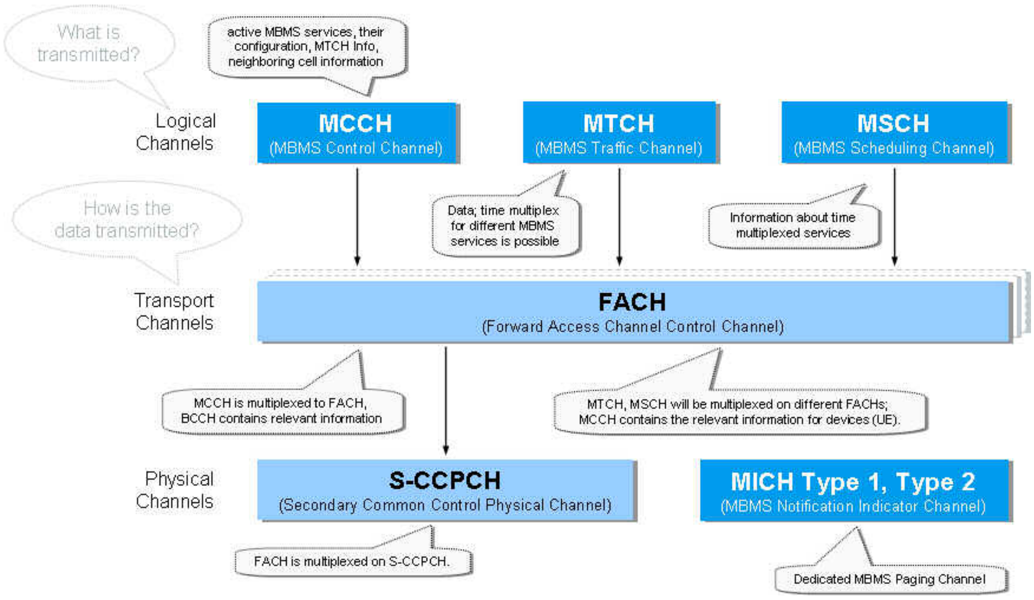


Figure 2: New 3G logical channels and physical channel due to MBMS

2.2 MBMS in LTE (3GPP Release 8 and 9)

MBMS in UMTS/WCDMA offers 6 mobile TV channels at a data rate of 128 kbps in a 5 MHz channel. Also the FDMA/TDMA- and CDMA-based access technologies for 2G (GSM) and 3G (WCDMA) are not well-suited for broadcast. All classical broadcast technologies (e.g. Digital Video Broadcast (DVB), Digital Audio Broadcast (DAB)) utilizing Orthogonal Frequency Division Multiplex (OFDM) as the underlying transmission scheme and so does LTE.

In addition two aspects are impacting the success for a MBMS service from a technical perspective. First, good coverage, even at the cell edge, and second low power consumption. Evolved MBMS (eMBMS) as defined in 3GPP Release 8 and 9 aims to tackle these aspects. The goal is to increase spectral efficiency at the cell edge up to 1bps/Hz while realizing a Single Frequency Network (SFN). In addition MBMS capabilities are increased compared to 3G, by offering 20 TV channels at a data rate of 256 kbps in a 5 MHz channel. However, eMBMS has not been identified being critical for commercial LTE deployment. Therefore the specification has been segmented by adding physical layer aspects already to 3GPP Release 8 and have higher layer and network related aspects completed within 3GPP Release 9.

LTE defines also a simpler and flatter network architecture than 3G, thus there is an impact offering MBMS over LTE. Figure 3 shows the involved network elements.

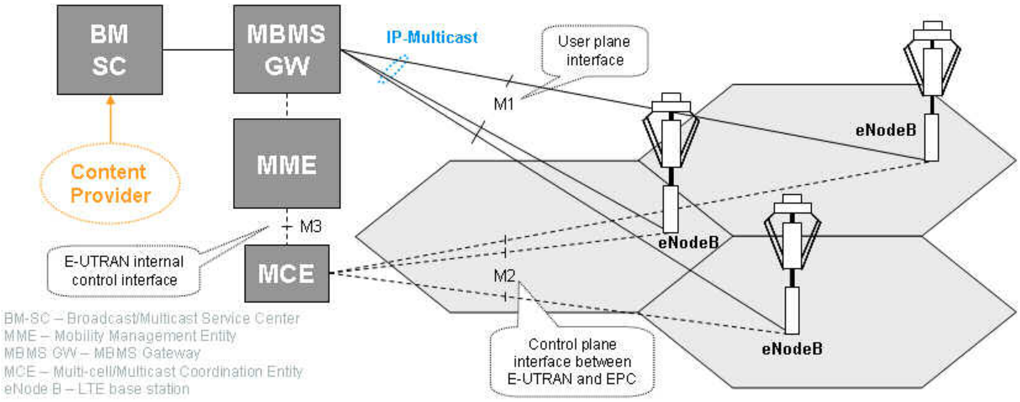


Figure 3: LTE network architecture for MBMS

The **BM-SC** (Broadcast/Multicast Service Center) has been already introduced with 3GPP Release 6. Its tasks are authentication, authorizing content provider, charging and the overall configuration of the data flow through the core network.

The **MBMS Gateway** (MBMS GW) is the logical node handling the multi-cast of IP packets from the BM-SC to all LTE base station (enhanced Node B, eNodeB or eNB). It further handles session control via the MME.

Mobile Management Entity (MME) is not a MBMS-only related network element. In fact it is part of the 3GPP Release 8 network architecture. The MME handles all tasks, that are non-related to the air interface. That means all Non-Access Stratum (NAS) protocols are terminated in the MME.

Key element for MBMS in LTE is the **MCE**, the Multi-cell/Multicast Coordination Entity. It coordinates the use of the same resources and transmission parameters across all radio cells that belong to a MBSFN area[1]. There are two ways of integrating the MCE to the network. Directly to the LTE base station. This is very cost effective as it is in most cases only a simple software upgrade to the existing hardware. The drawback is of course, that only cells that belong to that particular base station can form a MBSFN area. To avoid this limitation the MCE can be added as separate network element to the architecture.

In the following sections physical layer and higher layer aspects of eMBMS will be discussed.

2.2.1 MBSFN, MBSFN area

To support the broadcast effect required for MBMS radio cells, that are supposed to transmit the same content need to be synchronized. In that case the resulting signal will appear to a terminal as just one transmission over a time-dispersive radio channel. This is understood as Multimedia Broadcast Single Frequency Network (MBSFN). Radio cells that shall transmit the same content to multiple users will form a so called MBSFN area. Multiple cells can belong to such an area, and every cell can be part of up to eight MBSFN areas. There could be up to 256 different MBSFN areas defined, each one with an own identity. Once defined, MBSFN areas will not change dynamically. Further its not defined, that a terminal should receive content from multiple MBSFN areas simultaneously.

[1] See section 2.2.1 for MBSFN area definition.

Figure 4 shows an example of three different MBSFN areas. Here radio cell 7, 8 and 9 belong to more than one MBSFN area. In addition there could be radio cells in the MBSFN area that have a status of a "reserved cell", which means in this radio cell no MBMS transmission will be supported. This is the case for radio cell #4.

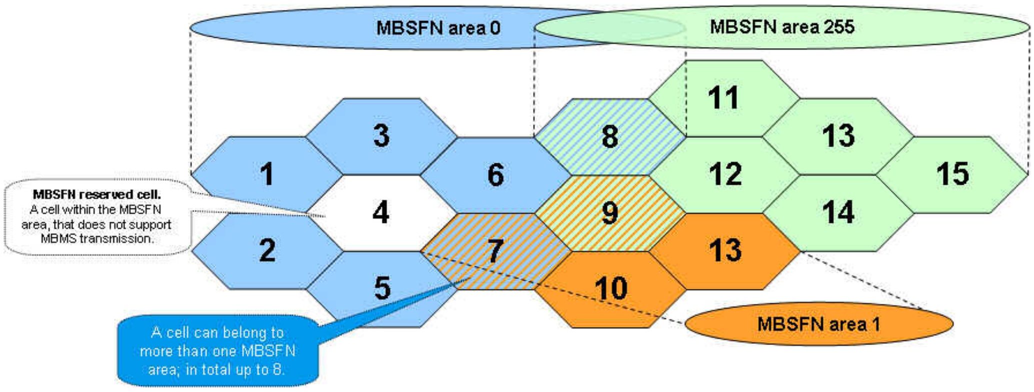


Figure 4: MBSFN area definition

2.2.2 New channels for MBMS

The support of MBMS in LTE requires new logical, transport and physical channels. Figure 5 gives an overview of the downlink channel concept in LTE and highlights the MBMS aspects.

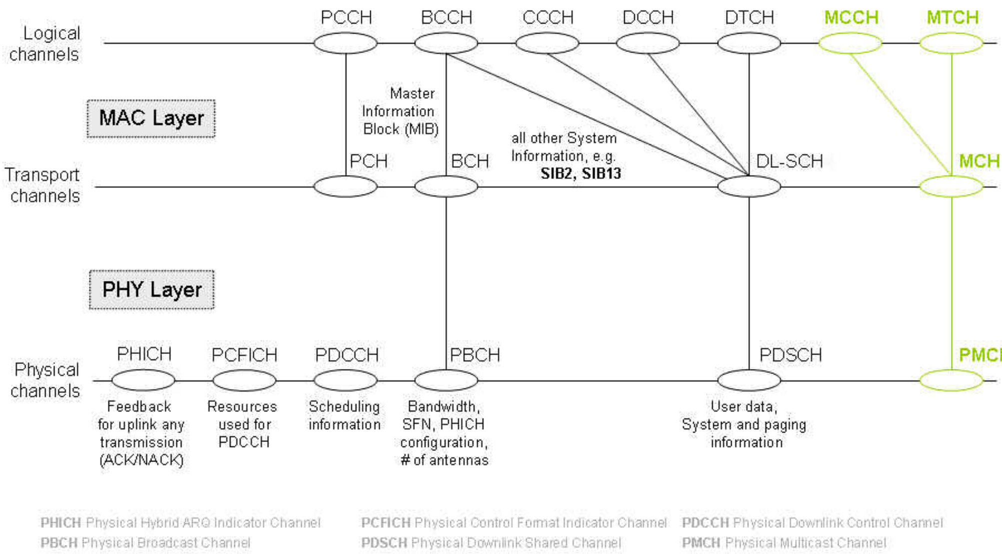


Figure 5: Enhanced channel architecture in LTE due to MBMS

There are two logical channels related to MBMS. The **Multicast Traffic Channel** (MTCH) carries data corresponding to a certain MBMS service. Large number of services per MBSFN area, may cause multiple MTCH. The channel uses Radio Link Control (RLC) Unacknowledged Mode (UM) for data transmission. Reason being, that there is no feedback in the uplink from a terminal in form of ACK/NACK due to the broadcast nature of the transmission.

The **Multicast Control Channel** (MCCH) provides necessary control information to receive MBMS services, including subframe allocation and used Modulation Coding Scheme (MCS). There is always one MCCH per MBSFN area. As for the MTCH RLC UM is used.

One or several MTCH and one MCCH are multiplexed at the Medium Access Control (MAC) onto the **Multicast Channel** (MCH), which is multiplexed to **the Physical Multicast Channel** (PMCH). Its worthwhile to note, that there is no multiple antenna transmission (no MIMO) defined for the PMCH. As the same data is transmitted by several LTE base station, all belonging to one MBSFN area, there is no dynamic adjustment of MCH resources by eNodeB (e.g. number of RB, MCS). The transport format is determined by the MCE and signalled via the MCCH to the terminal (UE).

2.2.3 Physical layer aspects of evolved MBMS

MBMS in LTE has certain impacts to the physical layer. Its start with the use of the cyclic prefix. Its an OFDM fundamental that the signal needs to arrive at the receiver within the cyclic prefix to avoid Inter-Symbol Interference (ISI). As we have multiple, but synchronized transmission from different source the expected delay spread is much higher than for generic LTE. Therefore and in order to support the broadcast effect even further eMBMS uses extended cyclic prefix only, where today's LTE networks are all based on normal cyclic prefix. An overview on cyclic prefixes in LTE and related subcarrier spacing is given in Table 1*Table* 1: *Cyclic prefix and subcarrier spacing in LTE* [1]

<table>
<tr><th>Configuration</th><th>OFDM symbol</th><th>Sub-carrier</th><th>Cyclic Prefix length in samples</th><th>Cyclic Prefix length in µs</th></tr>
<tr><td>Normal CP
Δf = 15 kHz</td><td>7</td><td rowspan="2">12</td><td>160 for 1st symbol
144 for other symbols</td><td>5.2 for 1st symbol
4.7 for other symbols</td></tr>
<tr><td>Extended CP
Δf = 15 kHz</td><td>6</td><td>512</td><td>16.7</td></tr>
<tr><td>Extended CP
Δf = 7.5 kHz</td><td>3</td><td>24</td><td>1024</td><td>33.3</td></tr>
</table>

Table 1:* Cyclic prefix and subcarrier spacing in LTE *[1]

As there are different CP's and subcarrier spacing defined for LTE, there are different modes for MBMS that take advantage of these. First, a mixed mode of MBMS and unicast transmission. In this mode the subcarrier spacing is 15 kHz and resources (subframes) are shared between MBMS data and generic LTE. See section 2.2.4 for further details. Second, there is an option for a dedicated mode. This is also called single-cell scenario, where the carrier is only used for MBMS data. In this case a different subcarrier spacing of 7.5 kHz will be used, offering a larger cyclic prefix of 33.3 µs which leads to a further improved broadcast effect.

In case of the mixed MBMS/unicast mode subframes that are supposed to carry MBMS data are divided into a Non-MBSFN and a MBSFN region. The Non-MBSFN region can occupy 1 or 2 OFDM symbols at the beginning of the subframe. In this region control channels like PCFICH, PDCCH and PHICH will be mapped to. This is required to schedule terminals to receive or transmit data, page them or provide feedback on their recent uplink transmission. In this region cell-specific reference signals and normal cyclic prefix will be used.

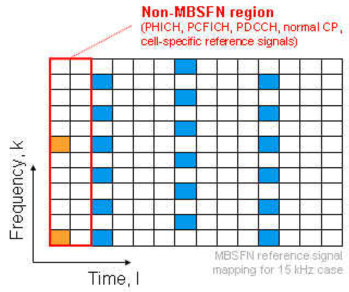


Figure 6: MBSFN reference signals

The MBSFN-region will carry the PMCH. This region will use extended cyclic prefix for a subcarrier spacing of 15 kHz [see Table 1] to cover the time difference of the cells that belong to that MBSFN area while transmitting the same content. In order to enable a coherent demodulation at the terminal as well as proper channel estimation the use of cell-specific reference signals is not sufficient. Thus reference signals for MBMS transmission have been adopted. Each cell belonging to the MBSFN area will transmit the same MBSFN reference signal pattern at the exact same time-frequency position. As it can be seen from Figure 6 the MBSFN reference signals have a tighter spacing in the frequency domain due to the time-dispersive or in other terms frequency-selective nature of the radio channel.

The initialization sequence for the MBSFN reference signal pattern depends – in contrast to the cell-specific reference signals – not on the physical cell identity. It depends on the MBSFN Identity provided by System Information Block Type 13 [see section 2.2.5].

$$c_{\mathrm{init}} = 2^9 \cdot \left(7 \cdot (n_s + 1) + l + 1\right) \cdot \left(2 \cdot N_{\mathrm{ID}}^{\mathrm{MBSFN}} + 1\right) + N_{\mathrm{ID}}^{\mathrm{MBSFN}}$$

Equation 1: Initialization sequence for MBSFN reference signals [1]

Also the scrambling for the PMCH is based on the MBSFN identity.

$$c_{\mathrm{init}} = \begin{cases} n_{\mathrm{RNTI}} \cdot 2^{14} + q \cdot 2^{13} + \lfloor n_s/2 \rfloor \cdot 2^9 + N_{\mathrm{ID}}^{\mathrm{cell}} & \text{for PDSCH} \\ \lfloor n_s/2 \rfloor \cdot 2^9 + N_{\mathrm{ID}}^{\mathrm{MBSFN}} & \text{for PMCH} \end{cases}$$

Equation 2: PMCH scrambling

n_s	Slot number within a radio frame
l	time domain index
N_{ID}^{MBSFN}	MBSFN identity
n_{RNTI}	Radio Network Temporary identifier
q	Code word number
N_{ID}^{cell}	Physical cell identity

2.2.4 Extended: SIB Type 2

The System Information Block Type 2 (SIB Type 2) carries all relevant information about common and shared channels in LTE. Due to this importance it is part of every single System Information (SI) message in LTE. With 3GPP Release 9 it has been extended to provide also information on MBMS. The new information element (IE) *MBSFN-SubframeConfig* defines which radio frames contain subframes, that can be used for MBMS [4]. These so called MBSFN subframes can be used by **ALL** MBSFN areas. First important information are the radio frame allocation period and a radio frame allocation offset. This two information now determines the periodicity when radio frames occur that contain MBSFN subframes. Further subframe allocation mode is defined within SIB Type 2. It could be one radio frame or four consecutive radio frames that allow MBSFN subframes.

At maximum 6 subframes out of a radio frame can be used for MBMS. Reason being that subframes 0 and 5 carry synchronization signals and broadcast channel, where subframes 0, 4, 5 and 9 can be used for paging depending on the defined paging cycle. Which of the 6 possible subframes are really used for MBMS is indicated by a bitmap. In terms of four radio frames being configured this bitmap is 24 bit long, otherwise 6 bit.

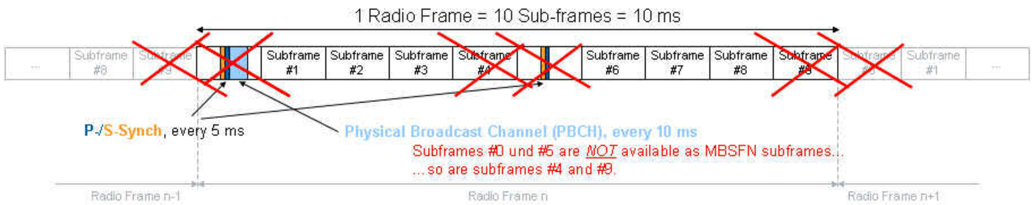


Figure 7: **Subframes available for MBMS**

In the following example a radio frame allocation period of 8 is assumed, with an offset of 2. All radio frames fulfilling SFN mod 8 = 2, will be radio frames that offer subframes to carry MBMS data. X-axis shows time as subframes, where y-axis is also time, but is showing increasing number of radio frames. As discussed above, grey marked subframes indicate that these subframes can not be used for MBMS at all. Further the subframe allocation mode has been assumed with four frames. The used bitmap indicates that the purple-highlighted subframes are used for MBMS. The remaining subframes that will not be used for MBMS can be used for standard LTE data transmission (point-to-point).

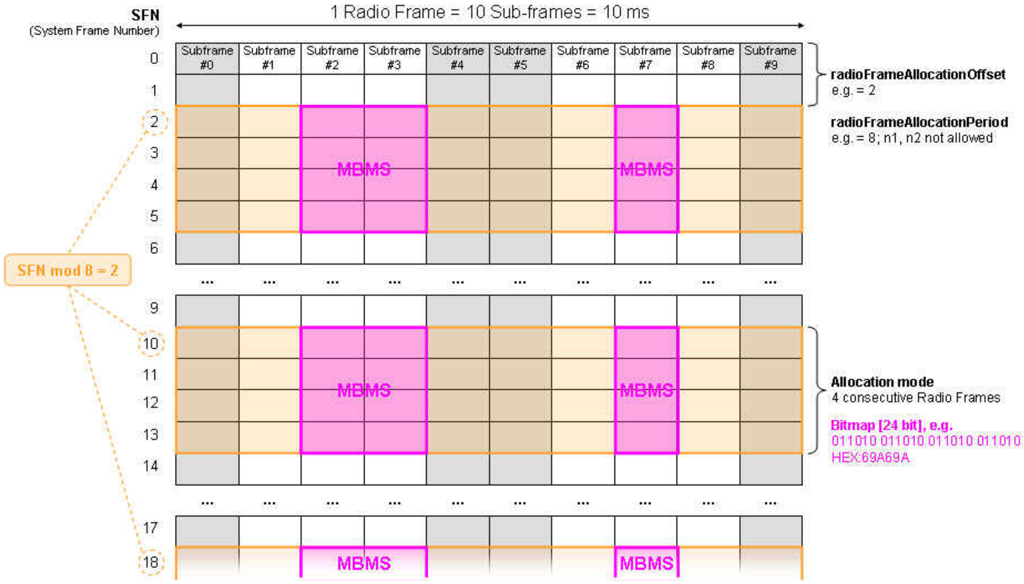


Figure 8: Determine MBSFN subframes by decoding SIB Type 2

2.2.5 NEW: SIB Type 13

As both, control and traffic channel (MCCH, MTCH) are mapped to the Multicast Channel (MCH), there is a kind of “chicken-and-egg”-problem as the one channel (MCCH) contains information how the other channel (MTCH) is organized and how to access it. This problem is solved while introducing the SIB Type 13, which provides the following information [4]:

- MBSFN identity (MBSFN ID)
- Non-MBSFN region length (1, 2 OFDM symbols)
- MCCH configuration

The MCCH configuration provides information on the repetition period for the MCCH, the MCCH offset as well as the actual subframe, where the MCCH is transmitted in as well as the MCS used for the MCCH. Coming back to our previous example, all this information may lead to the shown scenario. Selected repetition period of 32 means that every 32 radio frames the MCCH occurs in one of the MBSFN subframes. Which one is also determined by information part of the SIB Type 13, including the used modulation coding scheme. Its important to note that for the MCCH four modulation coding schemes are allowed: MCS index 2, 7 (both QPSK), 13 (16QAM), 19 (64QAM). For further details please refer to [3].

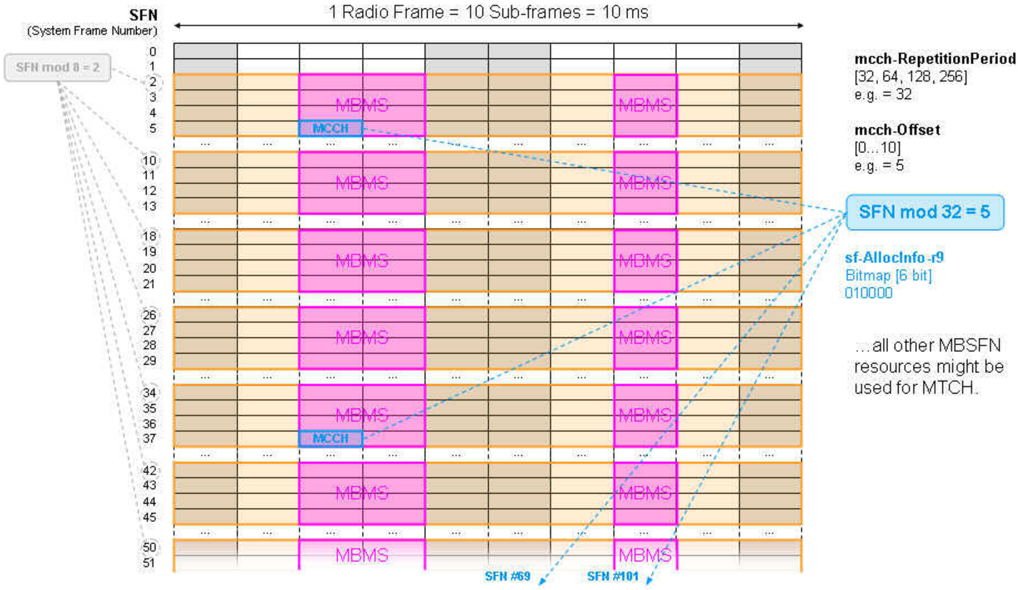


Figure 9: MCCH configuration determined from SIB Type 13

2.2.6 MCCH content

The MCCH defines always one MBSFN area and carries just one single message: *MBSFNAreaConfiguration*. This IE provides all required information for scheduling MBMS services. That includes all PMCH belonging to that particular MBSFN area and the configuration parameters for the session that are carried by the concerned PMCH. There could be up to 15 PMCH, where each one has up to 29 sessions (MTCH's). For each PMCH there will be the information which MBSFN subframes carries that PMCH (start, end) as well as the used modulation and coding scheme.

But first of all a **Common Subframe Allocation** (CSA) period is defined in number of radio frames. With that it can be determined how many subframes are available in total for MBMS within a period, that can be used for PMCH and thus for MTCH. The example in Figure defines a CSA of 16 radio frames, taking the previous examples into account that leads to in total 24 MBSFN subframes.

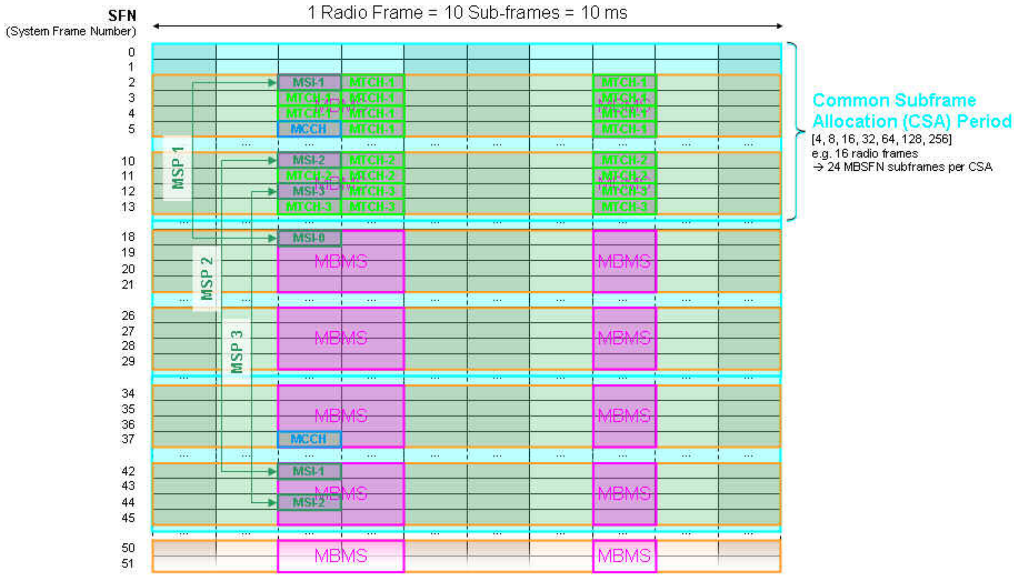


Figure 10: Common Subframe Allocation (CSA) period, MCH Scheduling Period (MSP), MCH Scheduling Information (MSI)

Each MCH, eventually carrying a MTCH, will be associated with a so called MCH Scheduling Period (MSP) to provide scheduling information for that MCH. At the beginning of a MSP the MCH Scheduling Information (MSI) is transmitted, a MAC control element, applicable to an MCH. This will inform the terminal about start and end for the associated MTCH.

3 Positioning methods in LTE

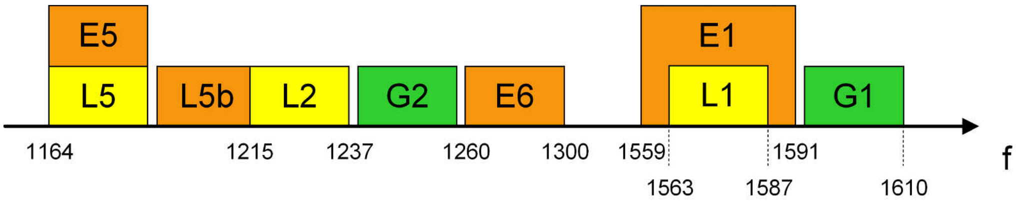
3.1 Introduction, (Assisted-)Global Navigation Satellite Systems

Positioning defines the process of determining the positioning and/or velocity of a device using radio signals.

Location Based Services, short LBS, are a significant element in today’s service portfolio offered via a network operators cellular network. It starts with simple things like answering the question “Where am I?” which is very often combined with determining points of interests, such as closest restaurants, shopping possibilities or finding a route from one point to another. Further social networks like facebook, Google Plus and others allow that status updates can be linked with the current position of the user.

Beside the commercial usage, there are also a safety aspects for positioning. As an example more than half of all emergency calls in the European Union (EU) are made using a mobile device. In almost 60% of all cases, the caller can not provide its current position accurately. Therefore the EU has issued a directive in 2003, where network operators are required to provide emergency services with whatever information is available about the location where the emergency call was made from. In the United States of Americas this is mandatory since a long time with the FCC’s Enhanced 911 mandate making the location of a cell phone available to emergency call dispatchers [10]. With this mandate the FCC has defined accuracy requirements for the different methods position estimation can be based on for county and country level, i.e. 67% of all emergency calls made on the county level need to be in a range of 50 m or less. These are quite high accuracy requirements, that need to be fulfilled and guaranteed no matter what the underlying position estimation technology is or in which environment the position will estimated in. The challenges for an accurate position estimation comes with the environment, means if the position is to be determined in rural and urban areas, city centre, outdoor or indoor and by mobility of the user. Based on these two categories the one or other technological approach might provide a better fit.

Determining a users or better device position is traditionally based on satellite-based position estimation using Global Navigation Satellite Systems (GNSS), like the Global Positioning System, short GPS. There are more systems in use and or currently established, such as the Russian GLONASS, the European GALLILEO system or systems that emerging countries like China and India are working or planning on. Figure 11 provides an overview about the top three systems and which frequencies they are using.



GALLILEO		GPS		GLONASS	
Signal	$f_{Carrier}$ [MHz]	Signal	$f_{Carrier}$ [MHz]	Signal	$f_{Carrier}$ [MHz]
E1	1575,420	**L1C/A**	1575,420	**G1**	1602±k*0.5625
E6	1278,750	**L1C**	1575,420	**G2**	1246±k*0.5625
E5	1191,795	**L2C**	1227,600	**k = -7 … 13**	
E5a	1176,450	**L5**	1176,450		
E5b	1207,140				

Figure 11: Frequencies being used by GPS, GALLILEO and GLONASS

Today the majority of all modern mobile devices, such as smart phones and tablets have an integrated GNSS receiver. To estimate a position properly the receiver needs to have an unobstructed line of sight to at least four satellites. And exactly this is one of the drawbacks using GNSS only. In a city center, or cities with narrow alleys and especially indoors line of sight reception of the low power radio signals coming from the satellites is not guaranteed, if not impossible. Figure 12 shows the availability of satellite signals in a city centre.

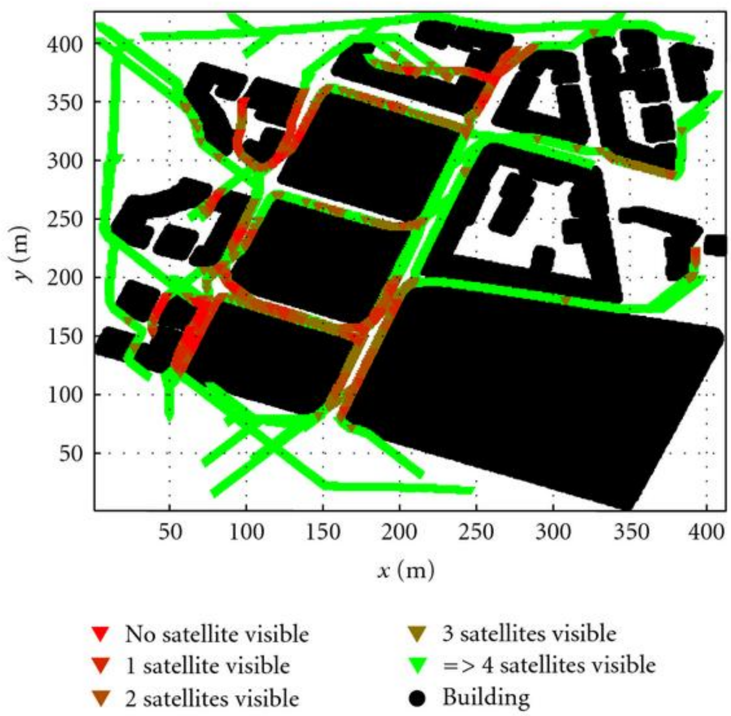


Figure 12: Number of visible GPS satellites in a city centre [13]

To overcome this situation, especially in an environment with poor signal conditions, Assisted-GNSS (A-GNSS) has been developed, where Assisted GPS is the natural example. By means of A-GPS a cellular network uses network resources to provide assistance data that helps the device to locate and utilize the available GPS satellites faster. A-GNSS reduces start-up and acquisition times, increases sensitivity and allow the device to reduce power consumption.

As statistics prove that almost 50% of all connections are made from inside, indoor remains a challenging environment. Often there is still an acceptable coverage by mobile radio signals, to determine the A-GPS information for instance, however this does not help if the satellites can not be detected due to no reception of GPS signals inside a building.

In such a critical scenario position estimation using mobile radio signals is the way forward. Such methods are not new. Already for the Global System of Mobile Communication (GSM) position estimation based on mobile radio signals had been defined. The following table compares position estimation based on (A-)GNSS, such as GPS with position estimation based on mobile radio systems.

(A-)GNSS	Mobile Radio Systems
Low bandwidth (typical 1 – 2 MHz)	High bandwidth (up to 20 MHz in LTE)
Very weak received signals	Comparatively strong received signals
Similar received power levels from all satellites	One strong signal from the serving base station, strong interference situation
Long synchronization procedures	Short synchronization procedures
Signal a-priori know due to low data rates	Complete signal not a-priori known to support high-data rates, only certain pilots
Very accurate synchronization of the satellites by atomic clocks	Synchronization of the base station not a-priori guaranteed
Line of sight (LOS) access as normal case, not suitable for urban / indoor areas	Non-line of sight (NLOS) access as normal case, suitable for urban / indoor areas
3-dimensional positioning	2-dimensional positioning

Table 2: Comparison GNSS and Mobile Radio Systems

However with LTE, as the mobile broadband technology of choice for the majority of network operators worldwide, additional methods have been standardized and existing ones were enhanced. The following sections will provide a detailed overview on positioning methods defined for LTE within 3GPP Release 9 based on mobile radio signals, beside traditional (A-)GNSS, which is not discussed in further details in this white paper. However A-GNSS is supported in LTE, where the required transfer of assistance data and information is covered in [11].

3.2 General aspects of LTE positioning

Generally an execution of a positioning method, independent if based on satellite or mobile radio signals, consist of three steps:

1. Providing initial assistance and information for position estimation.
2. Execution of certain measurements and reporting of measurement results.
3. Position estimation based on measurement results.

The supported positioning methods in LTE rely on the high-level network architecture shown in Figure 13. As one of the design goals for LTE was to decentralize everything, the network architecture has been defined in that way, that it is generally independent from the underlying network. There are three main elements involved in the process, the Location Service Client (LCS), the LCS Server (LS) and the LCS Target. A client, means the requesting service, is in the majority of the cases installed or available on the LCS target. This service obtains the location information by sending a request to the server. The location server is a physical or logical entity, that collects measurements and other location information from the device and base station and assists the device with measurement and estimating its position. The server basically process the request from the client and provide the client with the requested information and optionally with velocity information.

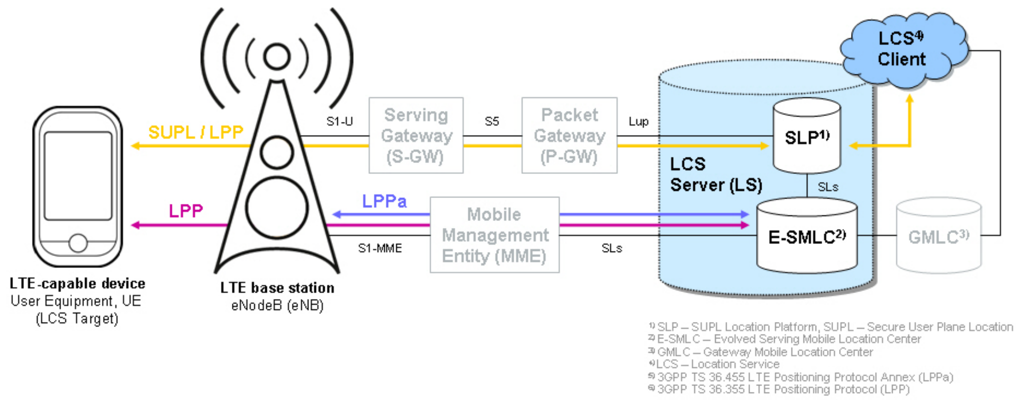


Figure 13: E-UTRA positioning network architecture

Now there are two different possibilities how the device (client) can communicate with the location server. Obviously there is the option to do this over the user plane, using a standard data connection, or over the control plane. In the control plane the E-SMLC, the Evolved Serving Mobile Location Center, is of relevance as location server, where for the user plane this is understood to be the SUPL Location Platform. SUPL stands for Service User Plane Location and is a general-purpose positioning protocol defined by the Open Mobile Alliance (OMA). Both E-SMLC and SLP are just logical entities and can be located in one physical server. Control plane signalling is supported for positioning due to being a more reliable and robust connection for a possible network congestion in an emergency scenario. A direct link between requesting service and location server is established to locate the position where the emergency call was made from.

Two protocols are used for the overall information exchange: the LTE Positioning Protocol (LPP) and the LTE Positioning Protocol Annex (LPPa) [11], [12]. The latter one is used for the communication between the Location Server and the eNode B, the LTE base station. The base station is in case of OTDOA in charge for proper configuration of the radio signals that are used by the terminal for positioning measurements, the so called positioning reference signals (PRS)[2]. It further provides information back to the E-SMLC, enables the device to do inter-frequency measurements if required and – based on the E-SMLC request – takes measurement itself and sends the results back to the server.

The LPP can be used in both: user plane and control plane. LPP is a point-to-point protocol, that allows multiple connections to different devices. The exchanged LPP messages and information can be divided into 4 categories:

1. UE positioning capability information transfer to the E-SMLC.
2. Positioning assistance data delivery from the E-SMLC to the device.
3. Location information transfer.
4. Session management.

The differentiation between supported positioning methods is based on two facts. First, who or what is the “measurement entity”, which could be only device or base station. Second, who or what is the “position estimation entity”. To classify the measurements the term “assisted” is used, for position calculation or estimation the term “based” is used. With that knowledge position methods supported in LTE can be further categorized. The following table provides an overview on supported positioning methods in LTE and which category they belong to.

Method	UE-based	UE-assisted	eNB-assisted	3GPP Release
A-GNSS	Yes Measurement: UE Estimation: UE	Yes Measurement: UE Estimation: LC	No	Rel-9
Downlink (OTDOA)	No	Yes Measurement: UE Estimation: LS	No	Rel-9
Enhanced Cell ID	No	Yes Measurement: UE Estimation: LS	Yes Measurement: eNB Estimation: LS	Rel-9
Uplink (UTDOA)	No	No	Yes Measurement: eNB Estimation: LS	Rel-11
RF Pattern Matching	?	?	?	Rel-11

Table 3: Supported positioning methods in LTE

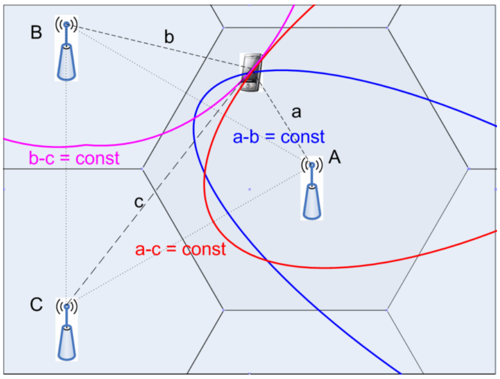
As Table 3 shows, there are in total four positioning methods in LTE, that are based on mobile radio signals: OTDOA, Enhanced Cell ID, UTDOA and RF pattern matching. The two later one are currently being standardized by 3GPP and will become part of 3GPP Release 11. These will be not further discussed in this document. OTDOA and Enhanced Cell ID are explained in the following sections.

[2] see section 3.3 for details.

3.3 OTDOA – Observed Time Difference of Arrival

3.3.1 Reference Signal Time Difference (RSTD) measurement

Position estimation is on measuring the Time Different Of Arrival (TDOA) on special reference signals, embedded into the overall downlink signal, received from different eNB's. Each of the TDOA measurement describes a hyperbola, where the two focus points (F1, F2) are the two measured eNB's. The measurement needs to be taken at least for three pairs of base station. The position of the device is the intersection of the three hyperbolas for the three measured base stations (A-B, A-C, B-C; see Figure 14).



Hyperbola principle:

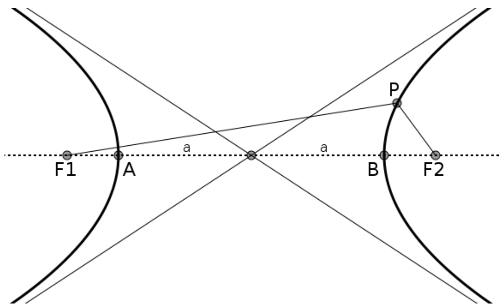


Figure 14: TDOA measurement based on hyperbolas

The measurement take between a pair of eNB's is defined as Reference Signal Time Difference (RSTD) [14]. The measurement is defined as the relative timing difference between a subframe received from the neighboring cell j and corresponding subframe from the serving cell i. These measurements are taken on the Positioning Reference Signals, the results are reported back to the location server, where the calculation of the position happens.

3.3.2 Positioning Reference Signals (PRS)

With 3GPP Release 9 Positioning Reference Signals (PRS) have been introduced for antenna port 6 as the Release 8 cell-specific reference signals are not sufficient for positioning.

What is an antenna port?

An antenna port is defined such that the channel over which a symbol on the antenna port is conveyed can be inferred from the channel over which another symbol on the same antenna port is conveyed. The device (UE) shall demodulate a received signal – which is transmitted over a certain antenna port – based on the channel estimation performed on the reference signals belonging to this (same) antenna port. The way the "logical" antenna ports are mapped to the "physical" TX antennas lies completely in the responsibility of the base station. There's no need for the base station to tell the UE.

The simple reason is that the required high probability of detection could not be guaranteed. A neighbor cell with its synchronization signals (Primary-/ Secondary Synchronization Signals) and reference signals is seen as detectable, when the Signal-to-Interference-and-Noise Ratio (SINR) is at least -6 dB. Simulations during standardization have shown, that this can be only guaranteed for 70% of all cases for the 3rd best-detected cell, means 2nd best neighboring cell. This is not enough and has been assumed an interference-free environment, which can not be ensured in a real-world scenario. However, PRS have still some similarities with cell-specific reference signals as defined in 3GPP Release 8. It is a pseudo-random QPSK sequence that is being mapped in diagonal patterns with shifts in frequency and time to avoid collision with cell-specific reference signals and an overlap with the control channels (PDCCH).

PRS are defined by bandwidth (N_{RB}^{PRS}), offset (Δ_{PRS}), duration (N_{PRS} = number of consecutive subframes) and periodicity (T_{PRS}). Its worth to be noted, that PRS bandwidth is always smaller than the actual system bandwidth (N_{RB}^{DL}). PRS are always mapped around the carrier frequency, the unused DC subcarrier in the downlink [Figure 15]. In a subframe where PRS are configured, typically no PDSCH is transmitted.

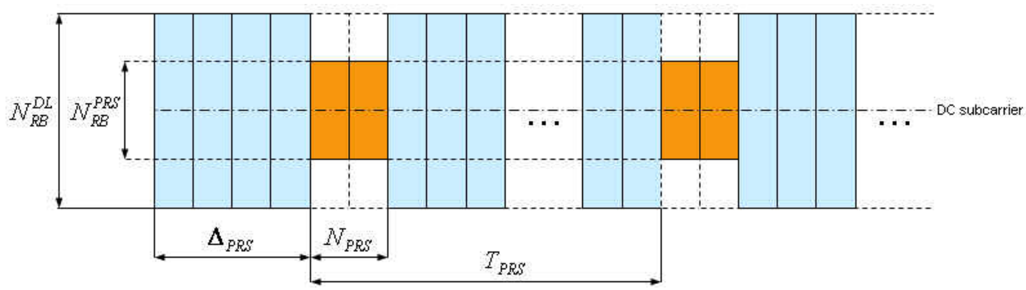


Figure 15: PRS configuration

PRS can be muted on certain occasions to further reduce inter-cell interference. All this information, means PRS configuration and PRS muting is provided via the LPP protocol from the Location Server.

3.4 Enhanced Cell ID

OTDOA is the method of choice for urban and indoor areas, where (A-)GNSS will not provide its best or no performance at all. Another method for position estimation in LTE is Enhanced Cell ID (E-CID), based on Cell of Origin (COO). With COO the position of the device is estimated using the knowledge of the geographical coordinates of its serving base station, in terms of LTE the eNB. The knowledge of the serving cell can be obtained executing a tracking area update or by paging. The position accuracy is in that case linked to the cell size, as the location server is only aware that the device is served by this base station. This method would of course not fulfill the accuracy requirements defined by the FCC. Therefore Enhanced Cell ID has been defined with LTE, mainly for devices where no GNSS receiver has been integrated. On top of using the knowledge of the geographical coordinates of the serving base station, the position of the device is estimated more accurately by performing measurements on radio signals. E-CID can be executed in three ways, using different types of measurements:

1. E-CID with estimating the distance from 1 base station.
2. E-CID with measuring the distance from 3 base station.
3. E-CID by measuring the Angle-of-Arrival (AoA) from at least 2 base station, better 3.

In the first two cases the possible measurements can be Reference Signal Received Power (RSRP), a standard quality measurement for Release 8 terminals, TDOA and the measurement of the Timing Advance (TADV) or Round Trip Time (RTT). In the first case the position accuracy would be just a circle. Method number 2 and 3 provide a position accuracy of a point, while measuring more sources. For case 1 and 2, the measurements are taken by the device, and are therefore UE-assisted. For case number 3 the measurements are taken by the base station and are therefore eNB-assisted (Figure 16).

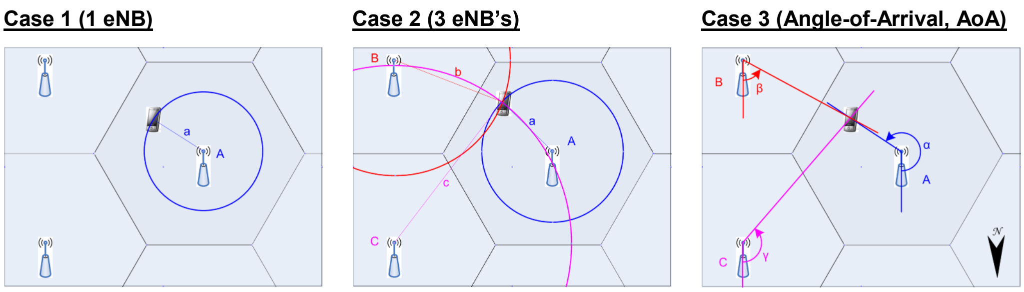


Figure 16: Enhanced Cell ID (E-CID) methods

The following sections will take a look on TDAV measurement and measurement of the Angle-of-Arrival (AoA).

3.4.1 Timing Advance (TDAV), Round Trip Time (RTT)

With 3GPP Release 9 the timing advance measurement has been enhanced, so that there are now a Type 1 and a Type 2 measurement. The Type 2 measurement relies on the timing advance estimated from receiving a PRACH preamble during the random access procedure. Type 1 is defined as the sum of the receive-transmit timing difference at the eNB (positive or negative value) and the receive-transmit timing difference at the terminal, that is always a positive value due. The base station measures first its own timing difference and report the device to correct its uplink timing per Timing Advance (TA) command, a MAC feature. The UE measures and reports its receive-transmit timing difference as well. Both timing differences allow the calculation of the Timing Advance Type 1, corresponding to the Round Trip Time (RTT). The RTT is reported to the location server, where the distance d to the base station is calculated using $d = c * RTT/2$, where c is the speed of light (Figure 17).

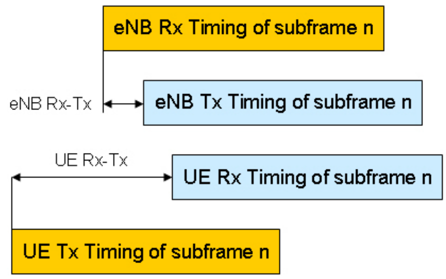


Figure 17: eNB and UE receive-transmit timing difference

3.4.2 Angle-of-Arrival (AoA) measurement

RTT, TA can be used for distance estimation, however they do not provide any information on direction. This can only be obtained from an Angle-of-Arrival (AoA) measurement. AoA is defined as the estimated angle of a UE with respect to a reference direction which is geographical North, positive in a counter-clockwise direction, as seen from an eNB. This is shown in the Figure 18.

The base station can usually estimate this angle on any part of the uplink transmission, however typically Sounding Reference Signals are used for this purpose. But the Demodulation Reference Signals (DM-RS) provide also sufficient coverage. Further the antenna array configuration has a key impact to the AoA measurements. Basically the larger the array, the higher the accuracy. With a linear array of equally spaced antenna elements the received signal at any adjacent elements is phase-rotated by a fixed amount THETA. And the value for THETA is a function of the AoA as

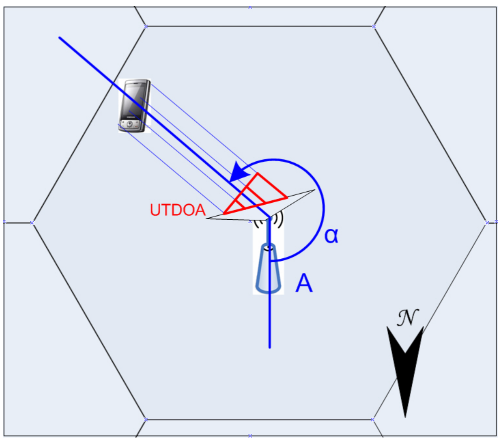


Figure 18: Angle-of-Arrival (AoA) measurement

well as the antenna element spacing and
carrier frequency.

4 LTE MIMO: dual-layer beamforming

The LTE system targets for high data rate, high system capacity and large coverage to provide excellent user experience. Beamforming (BF) is one of the technologies helping to reach this goal, specifically by improving the cell edge performance. LTE as specified in 3GPP Release 8 already supports single-layer beamforming based on user-specific Reference Symbols (also referred to as Dedicated RS or DRS or DM RS). Single-layer beamfroming uses only one codeword, i.e. one transport block. In general the solution allows to direct the beam towards a specific UE through position estimation at the eNodeB (direction of arrival). The eNodeB generates a beam using the array of antenna elements, and then applies the same precoding to both the data payload and the UE-specific reference signal with this beam. It is important to note that the UE-specific reference signal is transmitted in a way such that its time-frequency location does not overlap with the cell-specific reference signal. As the scheme is not involving any UE feedback mechanism, it is specifically suited for LTE in TDD mode of operation, leveraging the reciprocity of the propagation channel in DL and UL direction.

To further evolve the DRS based beamforming technology, multi-layer beamforming has been included in LTE Release 9. Extending the Release 8 single-layer beamforming operation to a multi-layer version provides a good opportunity for a UMTS LCR-TDD operator to migrate its network to a TD-LTE network while continuing to use DRS based beamforming technology and leveraging the installed base of potentially existing antenna arrays.

4.1 Physical layer details:

As mentioned above beamforming requires UE specific reference symbols. With dual layer beamforming using two codewords (transport blocks) and two antennas, the existing UE specific reference symbol scheme in [1], section 6.10.3 had to be extended. The position of the UE specific reference symbols on antenna port 7 and 8 are illustrated in Figure 19.

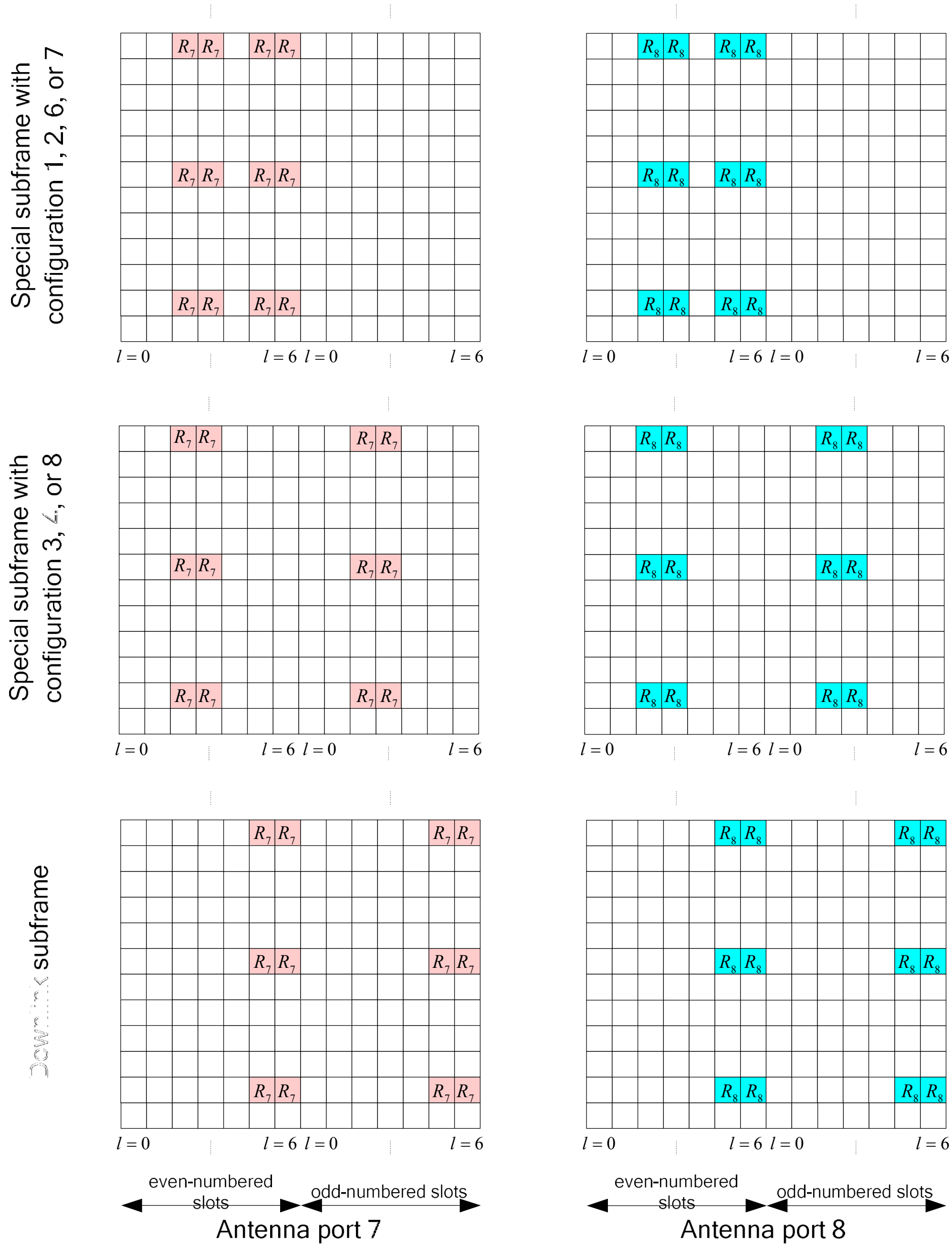


Figure 19: Mapping of UE-specific reference signals, antenna ports 7 and 8 (normal cyclic prefix)

In addition signalling usage of dual layer beamforming to the UE required a new Downlink Control Information (DCI) format 2B (see [2]). DCI 2B format includes the following information:

- Resource allocation header (resource allocation type 0/1)
- Resource block assignment
- TPC command for PUCCH
- DL assignment index (TDD only)
- HARQ process number
- Scrambling identity

- And for each transport block
  - Modulation and coding scheme
  - New data indicator
  - Redundancy version

If both transport blocks are enabled, the number of layers equals two. Transport block 1 is mapped to codeword 0 and transport block 2 is mapped to codeword 1. Antenna ports 7 and 8 are used for spatial multiplexing. In case one of the transport blocks is disabled, the number of layers equals one.

In general dual layer beamforming can be configured either with or without PMI/RI reporting depending on whether the parameter *pmi-RI-Report* is configured by higher layers. In case PMI/RI reporting is configured the feedback algorithm is the same as used for MIMO spatial multiplexing in 3GPP Release 8, i.e. rank indication (RI) and Precoding Matrix Indication (PMI) will be reported to the eNodeB.

A new transmission mode 8 to reflect dual layer beamforming with two codewords has been added in [3] as illustrated in Table 4 below.

Transmission mode	DCI format	Search Space	Transmission scheme of PDSCH corresponding to PDCCH
Mode 1	DCI format 1A	Common and UE specific by C-RNTI	Single-antenna port, port 0 (see subclause 7.1.1)
	DCI format 1	UE specific by C-RNTI	Single-antenna port, port 0 (see subclause 7.1.1)
…			
Mode 4	DCI format 1A	Common and UE specific by C-RNTI	Transmit diversity (see subclause 7.1.2)
	DCI format 2	UE specific by C-RNTI	Closed-loop spatial multiplexing (see subclause 7.1.4)or Transmit diversity (see subclause 7.1.2)
…			
Mode 8	DCI format 1A	Common and UE specific by C-RNTI	If the number of PBCH antenna ports is one, Single-antenna port, port 0 is used (see subclause 7.1.1), otherwise Transmit diversity (see subclause 7.1.2)
	DCI format 2B	UE specific by C-RNTI	Dual layer transmission; port 7 and 8 (see subclause 7.1.5A) or single-antenna port; port 7 or 8 (see subclause 7.1.1)

Table 4: LTE Rel9 transmission modes including transmission mode 8 for dual layer beamforming

5 Public Warning System (PWS)

There has been an interest to ensure that the public has the capability to receive timely and accurate alerts, warnings and critical information regarding disasters and other emergencies irrespective of what communications technologies they use. As has been learned from disasters such as earthquakes, tsunamis, hurricanes and wild fires; such a capability is essential to enable the public to take appropriate action to protect their families and themselves from serious injury, or loss of life or property. In some cases, warnings are already made via commercial or government-owned radio or television broadcast facilities. With the significant deployment of cellular mobile networks and their ability to provide broadcast services, warnings can also be transmitted to large numbers of subscribers via their user device. Support over cellular mobile networks is to supplement other notification methods. The interest to enhance the reliability, resiliency, and security of Warning Notifications to the public has been the driving force for the PWS feature.

The high level requirements for the feature are summarized below:

- PWS shall be able to broadcast Warning Notifications to multiple users simultaneously with no acknowledgement required.
- PWS shall be able to support concurrent broadcast of multiple Warning Notifications.
- Warning Notifications shall be broadcast to a Notification Area which is based on the geographical information as specified by the Warning Notification Provider.
- PWS capable UEs (PWS-UE) in idle mode shall be capable of receiving broadcasted Warning Notifications.
- PWS shall only be required to broadcast Warning Notifications in languages as prescribed by regulatory requirements.
- Warning Notifications are processed by PWS on a first in, first out basis, subject to regulatory requirements.
- Reception and presentation of Warning Notifications to the user shall not pre-empt an active voice or data session.
- Warning Notifications shall be limited to those emergencies where life or property is at imminent risk, and some responsive action should be taken.

5.1 Commercial Mobile Alert System (CMAS)

An initial support for alerting end users was already included in LTE Release 8 known as the ETWS feature, i.e. Earthquake and Tsunami Warning Systems. PWS extends the possibilities from ETWS by providing:

- support for multiple parallel warning notifications
- support for replacing and cancelling a warning notification
- support for repeating the warning notification with a repetition period as short as 2 seconds and as long as 24 hours
- support for more generic "PWS" indication in the paging indication

The principle for notification of warning messages is maintained. I.e. the end user devices receives dedicated paging upon availability or change of warning messages. The E-UTRAN performs scheduling and broadcasting of the “warning message content” received from the Cell Broadcast Center (CBC), which is forwarded to the E-UTRAN by the MME. The warning messages itself is then broadcasted in dedicated system information blocks. ETWS messages are included in *SystemInformationBlockType10* and *SystemInformationBlockType11*. The enhancement in LTE Release 9 is named CMAS developed for the delivery of multiple, concurrent warning notifications. The CMAS warning notifications are broadcast in *SystemInformationBlockType12*. Note that paging is used to inform CMAS capable UEs in both RRC_IDLE and RRC_CONNECTED state. If the UE receives a paging message including the *cmas-Indication*, it shall start receiving the CMAS notifications according to *schedulingInfoList* contained in *SystemInformationBlockType1*. See below the content of the information element *SystemInformationBlockType12.*

```
SystemInformationBlockType12 ::=    SEQUENCE {
    messageIdentifier                   BIT STRING (SIZE (16)),
    serialNumber                        BIT STRING (SIZE (16)),
    warningMessageSegmentType           ENUMERATED {notLastSegment,
lastSegment},
    warningMessageSegmentNumber         INTEGER (0..63),
    warningMessageSegment               OCTET STRING,
    dataCodingScheme                    OCTET STRING (SIZE (1))
    OPTIONAL,   -- Cond Segment1
    ...
}
```

SystemInformationBlockType12 field descriptions
messageIdentifier
Identifies the source and type of CMAS notification.
serialNumber
Identifies variations of a CMAS notification.
warningMessageSegmentType
Indicates whether the included CMAS warning message segment is the last segment or not.
warningMessageSegmentNumber
Segment number of the CMAS warning message segment contained in the SIB. A segment number of zero corresponds to the first segment, one corresponds to the second segment, and so on.
warningMessageSegment
Carries a segment of the Warning Message Contents IE defined in TS 36.413.
dataCodingScheme
Identifies the alphabet/coding and the language applied variations of a CMAS notification.

Table 5: SystemInformationBlockType12 information element [4]

In order to satisfy the requirement of replacing or canceling warning messages new procedures between eNB and MME are introduced as illustrated in Figure 20 and Figure 21 below.

The *Write-Replace* procedure is initiated by the MME by sending *Write-Replace Warning Request* message containing at least the message identifier, warning area list, information on how the broadcast should be performed, and the contents of the warning message to be broadcast. The eNB responds with *Write-Replace Warning Response* message to acknowledge that the requested PWS warning message broadcast was initiated. ETWS and CMAS are independent services and ETWS and CMAS messages are differentiated over S1 in order to allow different handling.

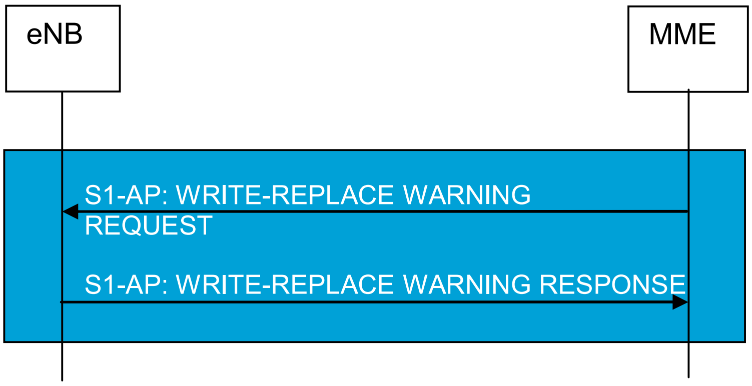


Figure 20: Write-Replace Warning procedure

The *Kill* procedure is used to stop the broadcasting of a PWS warning message. The procedure is initiated by the MME sending the *Kill Request* message containing at least the message Identifier and serial number of the message to be killed and the warning area list where it shall be killed. The eNB responds with a *Kill Response* message to acknowledge that the requested PWS message broadcast delivery has actually been stopped.

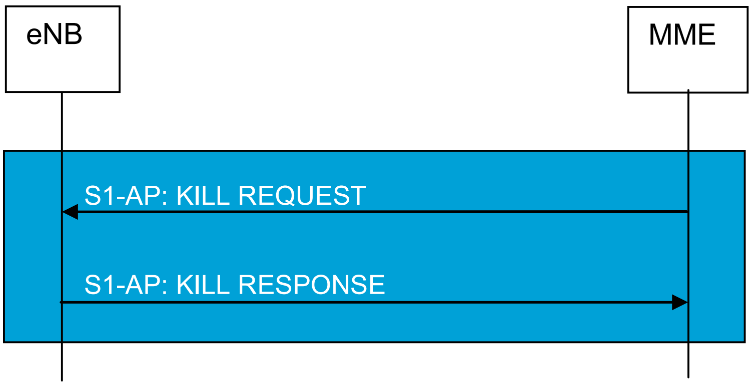


Figure 21: Kill procedure

6 RF requirements for multi-carrier and multi-RAT base stations

Traditionally requirements for base stations have been specified on a per technology basis. I.e. base stations were designed to transmit either radio technology, for instance GSM or UMTS. In the meantime base stations architectures have become flexible in supporting multiple radio access technologies (RATs) as well as multiple carrier frequencies. 3GPP standardisation did respond to this technology development within 3GPP Release 9 by creating a dedicated specification for multi-carrier and multi-RAT base stations using the expression Multi Standard Radio (MSR) base stations. The requirements for MSR are in most parts specified in [5], while many requirements are also specified through normative references to the respective single-RAT specifications. The specification cover the radio access technologies GSM, UMTS/HSPA and LTE. There are three types of requirements:

- **Generic MSR requirement:** A common generic requirement is specified in [5] that applies for all RATs supported by the base station. In some cases, there are additional requirement(s) that apply only in some specific Band Category. In this case there are no references to the single-RAT specifications.
- **Generic MSR requirement, with additional single-RAT requirements:** A common generic requirement is specified in [5]. In addition some single RAT requirement(s) apply, included by normative reference(s) to the single-RAT specification(s).
- **Single-RAT only requirements:** In this case, no common generic requirement is defined. The existing single-RAT requirement applies for each RAT, included by normative reference(s) to the single-RAT specification(s).

Figure 22 illustrates the specific terms used for testing a base station that is running multiple RATs and multiple carrier frequencies. In addition to the requirements specified in [5], [6] determines the test methods and conformance requirements.

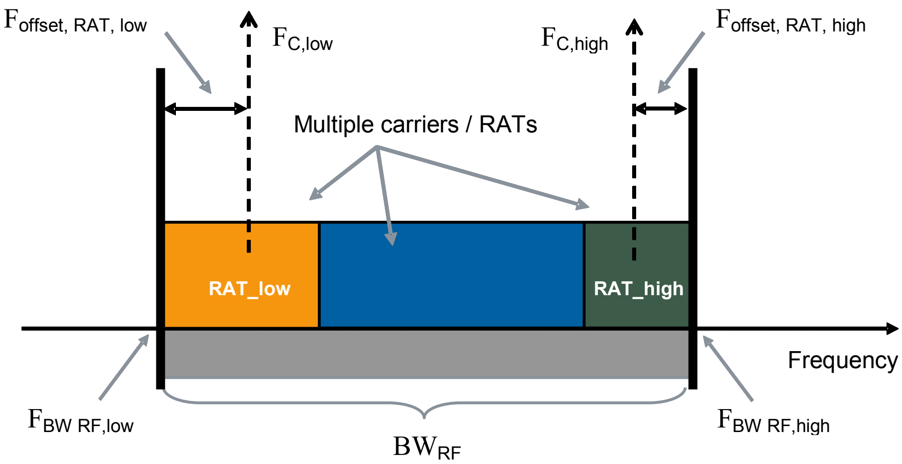


Figure 22: Illustration of RF bandwidth related symbols and definitions for Multi-standard Radio [5]

Note that MSR specifications cover base stations intended to cover general purpose applications in wide area scenarios. I.e. local area and home access scenarios, sometimes also named micro and pico scenarios, have not been defined yet.

6.1 Operating bands and Band Categories

According to [5] three different band categories are defined:

- Band Category 1 (BC1): Bands for E-UTRA FDD and UTRA FDD operation
- Band Category 2 (BC2): Bands for E-UTRA FDD, UTRA FDD and GSM/EDGE operation
- Band Category 3 (BC3): Bands for E-UTRA TDD and UTRA TDD operation

Additionally the frequency bands for MSR base stations in FDD and TDD mode are summarized in Table 6 and Table 7 below.

MSR and E-UTRA Band number	UTRA Band number	GSM/EDGE Band design-nation	Uplink (UL) BS receive UE transmit [MHz]	Downlink (DL) BS transmit UE receive [MHz]	Band category
1	I	-	1920 – 1980	2110 – 2170	1
2	II	PCS 1900	1850 – 1910	1930 – 1990	2
3	III	DCS 1800	1710 – 1785	1805 – 1880	2
4	IV	-	1710 – 1755	2110 – 2155	1
5	V	GSM 850	824 – 849	869 – 894	2
6(1)	VI	-	830 – 840	875 – 885	1 (1)
7	VII	-	2500 – 2570	2620 – 2690	1
8	VIII	E-GSM	880 – 915	925 – 960	2
9	IX	-	1749.9 – 1784.9	1844.9 – 1879.9	1
10	X	-	1710 – 1770	2110 – 2170	1
11	XI	-	1427.9 – 1447.9	1475.9 – 1495.9	1
12	XII	-	699 – 716	729 – 746	1
13	XIII	-	777 – 787	746 – 756	1
14	XIV	-	788 – 798	758 – 768	1
15	XV	-	Reserved	Reserved	
16	XVI	-	Reserved	Reserved	
17	-	-	704 – 716	734 – 746	1 (2)
18	-	-	815 – 830	860 – 875	1 (2)
19	XIX	-	830 – 845	875 – 890	1
20	XX	-	832 – 862	791 – 821	1
21	XXI	-	1447.9 – 1462.9	1495.9 – 1510.9	1

Table 6: Paired bands in E-UTRA, UTRA and GSM/EDGE

(1) This band is for UMTS only
(2) This band is LTE only

MSR and E-UTRA Band number	UTRA Band number	TDD Frequency Band [MHz]	Band category
33	a)	1900 MHz – 1920 MHz	3
34	a)	2010 MHz – 2025 MHz	3
35	b)	1850 MHz – 1910 MHz	3
36	b)	1930 MHz – 1990 MHz	3
37	c)	1910 MHz – 1930 MHz	3
38	d)	2570 MHz – 2620 MHz	3
39	f)	1880 MHz – 1920 MHz	3
40	e)	2300 MHz – 2400 MHz	3

Table 7: Unpaired bands in E-UTRA and UTRA

7 Home eNodeB specification (femto-cell)

LTE femtocells, also known as Home eNodeB (HeNB) in 3GPP, are part of the 3GPP Release 9 LTE specifications. 3G femtocells are already deployed around the world and operate as residential, enterprise or outdoor hotspots as low-power access points to provide better coverage and higher capacity. In order to provide the LTE experience for user through femtocells, some new requirements were adopted to Release 9. Figure 23 provides the basic architecture of a femto deployment at home. The HeNB GW serves as a concentrator for the C-Plane, specifically the S_1-MME interface. The S_1-U interface from the HeNB may be terminated at the HeNB GW, or a direct logical U-Plane connection between HeNB and S-GW may be used. X_2 connectivity between HeNBs is not supported.

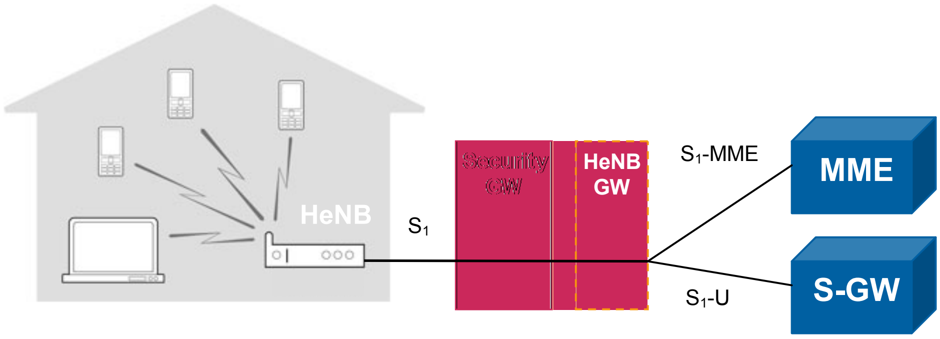


Figure 23: HeNB Architecture and interfaces

7.1 New RAN functionalities

The new introduced hybrid cell concept is an addition to the already known closed and open access control mechanisms of Release 8, where a closed access allows only access for subscribed users (Closed Subscriber Group CSG) in contrast to the open access, where all users are allowed to access the HeNB with its offered services. A hybrid cell provides open access to all users, but subscribed users can be handled with priority in contrast to unsubscribed users.

In case of the UE is no longer a member of the CSG the MME (Mobility Management Entity) sends membership information to the HeNB to try a handover of the UE to a non-CSG cell. In case the cell is a hybrid cell, the UE can stay within the same cell but handled as a non-CSG member in terms of quality of service.

Access control will be done by the MME based on the CSG ID and the membership status of the subscriber. In case the target cell is a hybrid cell, the UE belonging to the CSG will be handled with prioritization.

The inbound handover from a macro eNB to a HeNB was not supported by Release 8. For the handover decision to a HeNB (Release 9), the marco eNB has to acquire some UE measurements from the target HeNB.

For efficiency reasons a newly defined proximity report can be configured within the RRC reconfiguration message. With this report the UE is able to send in the uplink a “proximity indication” to the source eNB. In order to reduce network load when many UE’s send their proximity indicator information, a so-called prohibit proximity timer was introduced.
The UE is able to identify that it is nearby a HeNB, and can inform the network components to prepare the necessary actions for a handover to the HeNB.

CSG related parameters stored on the SIM card of the UE were already defined in Release 8. Release 9 introduces some additional parameters controllable by the operator. The entries on the USIM are: PLMN identifier, CSG Identifier, Home eNB name and CSG type.

The number of deployed HeNB’s might be very high and the location is not always accessible by operators for onsite maintenance, especially when the HeNB is installed in private homes. Therefore the HeNB will be managed via the HeNB management system (HeMS). The HeMS can reboot the HeNB, start or stop transmissions on certain frequencies or allow downloads of software. Fault management and security management are further tasks of the HeMS.

The unpredictable deployment of HeNB and the potential high number of HeNB’s in a certain area were already discussed in a 3GPP Release 8 technical report (TR 25.820). In Release 9 this leads to specific RF requirements for HeNB’s. One of the biggest challenges is interference handling from/to macro cells and other HeNB’s. To pay attention to the interference reduction techniques in uplink and downlink 3GPP released two technical reports on LTE FDD [7] and LTE TDD [8].

Home BS are characterised by requirements derived from Femto Cell szenarios.
In order to limit interferences from HeNB’s to macro eNB’s the transmitter output power of the HeNB was limited. According to [9] the Home BS maximum output power is defined to +20 dBm for one transmit antenna port, +17dBm for two transmit antenna ports and +14dBm for four transmit antenna ports respectively. To minimize the interference level the Home BS has to adjust the TX output power on adjacent channels licensed to other operators in the same area while optimizing coverage.

In order to reduce the unwanted interferences, one has to identify the interferences before taking any actions. The HeNB could use it’s own receiver to monitor the uplink interferences and measure the received interference power. On this way a nearby UE transmitting to a macro eNB could be identified. On the other hand, information transmitted from a macro eNB itself or an adjacent HeNB can carry useful information for the HeNB itself. This type of measurements requires an additional downlink receiver to listen to the neighbour base station. This mode is called the network listening mode or sniffer mode. In addition [9] defines different RF requirements for HeNB compared to other types of base stations, i.e. local area or wide area BS. These are mainly lower maximum output power, lower dynamic range, larger unwanted and spurious emission levels, lower intermodulation requirements or more relaxed frequency error and sensitivity levels. Accordingly new conformance test cases have been added in [15].

8 Self Organizing Networks

The complexity of a network is increasing for every new release, due to multi-technology environments, tight spectrum usage, advanced radio interface features and parameterization. So, setting the parameters by hand and optimizing them becomes a more and more time consuming task, resulting in enhanced costs for network operation.
In addition, manual parameter setting is a rather static way to control the network. The optimal network settings are often time dependent, reflecting the changes of user behavior and location. Therefore, settings should be changed in a fast way and as flexible as possible. The only way to cope with these requirements is to do these settings autonomously.
Whereas in these scenarios the autonomous configuration is a highly desirable feature, it is a must for the new emerging so called Heterogeneous Networks. Here, macro, micro, pico and femto cells are all transmitting and receiving in the same frequency bands, leveraging each other in coverage and capacity. By construction these networks are very complex, and for the case of femto cells the parameters are even, at least partially, out of control to the operator.
So, the concept of Self Organizing Network (SON) was introduced from LTE Release 8 on in order to reduce OPEX and to improve the network quality. The settings of network parameters are automated, supported by measurements of the UE and eNBs. Thus, the SON can be considered as a kind of control loop, a concept which was already successfully implemented in different layers of the protocol stack. This SON control loop acts on parameters which are visible to the outside world, like transmit power or antenna tilt, but also on internal parameters like the handover (HO) parameters or the neighborhood list.

8.1 Architecture

Figure 24 shows the network components which are essential for SON. Depending on the involved nodes, the architectures are assigned as

- Centralized Architecture: In this architecture, the algorithms are controlled by the O&M center. Consequently, the execution speed is rather slow, however, a lot of eNBs can be used for the collection of network information and the algorithms.
- Distributed Architecture: The SON entities are in the eNBs, with an information exchange over the X_2 or S_1 interface. In this approach the number of involved eNBs may not be too high. The reaction time is much shorter allowing a network reaction on changing environment conditions in a very fast way. In the limit of having only one eNB, this architecture is also assigned as Localized Architecture.
- Hybrid Architecture: The combination of both architectures, where the algorithms are distributed between the O&M and different eNBs.

Using the Distributed Architecture does not mean that the O&M is not involved at all. It may configure value ranges for the parameters to be optimized, whereas the SON algorithms in the eNBs select the optimal value within this range.

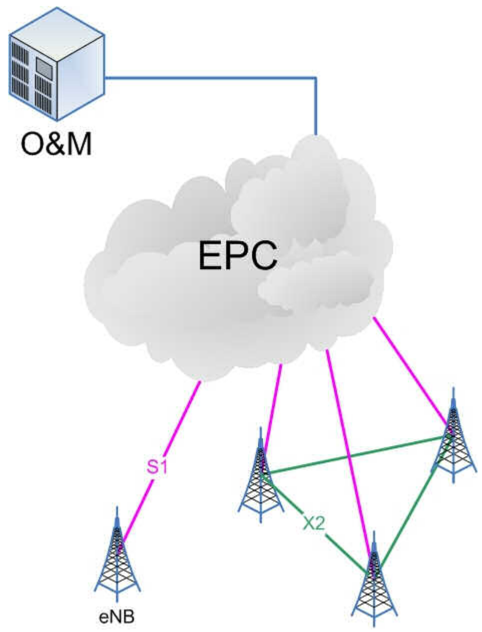


Figure 24: Network components for the SON architecture

8.2 SON Processing

The processes in SON are visualized in Figure 25. After switching on the eNB, the so called *Self Configuration* starts. During this time, the eNB is already physically connected with the network, but the RF is still switched off. An IP address and a connection to an O&M is assigned to the eNB. After an authentication in the network, the eNB gets an association to the MME and S-GW, and the connections to the core (S_1) and to the neighbored eNBs (X_2) are established. If available there may be a software update. Also the physical cell identities (PCI) for all supported cells in the eNB are assigned here, as these are required to go on air. Note that this assignment must be done without feedback from the UE.

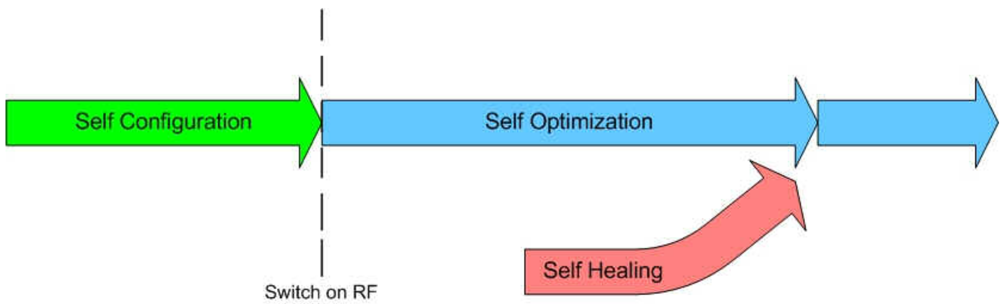


Figure 25: Operational Processes in SON

After these basic setup procedures, the eNB gets the initial radio configuration. This is comprised by the initial neighbor list, the coverage and capacity related parameter configuration like transmission power, antenna tilt, and all remaining parameters for operation. These parameters are finally optimized at the next stage, the *Self Optimization*.

This stage starts by switching on the RF. Mobiles may now connect with the cells and return feedback to improve the initial radio configuration and also to adopt them to (time dependent) traffic load or measured propagation conditions. For this feedback, existing RRC measurements have been extended.
In the case of a failure, the so called *Self Healing* applies. Depending on the failure reason the eNB either switches to a spare part (if existing) in case of a hardware failure, or reloads a former software when the failure was caused by a not properly running software update. When none of these remedies work, the remaining eNBs change their settings in order to fill the coverage gap created by the failure.
So, with SON, rolling out new eNBs shall be a kind of Plug and Play system, having only a single site visit to install and operate the station. All parameter settings, including the changes in the network neighbourhood, shall work in an autonomous way.

8.3 Use Cases for Self Configuration

The use cases for Self Configuration have been defined in Release 8. There was an update in Release 9 to take the CSGs of the Femto-Cells into account.

8.4 Use Cases for Self Optimization

These use cases have been started with Release 9 and are expanded in later releases. They comprise support for the optimization of HO parameters, balancing the load between different cells or eNBs, and an optimization of the RACH settings.

8.4.1 Mobility Robustness Optimization

The goal of Mobility Robustness Optimization (MRO) is to find the pertinent HO trigger to the correct target cell (Figure 26). Finding these optimal settings is often a time consuming task which may be too costly in practise. In addition, the optimal settings may depend on the momentary radio conditions. In this case, a manual optimization is not possible at all.

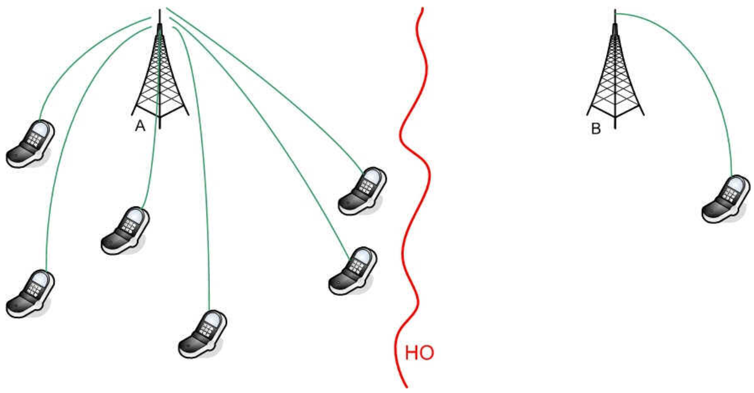


Figure 26: Handover scenario. The red line indicates the locations, where a handover shall be triggered.

Effects caused by incorrect HO parameter settings may be classified in three categories:

- Unnecessary or missing HOs: In this category are the so called ping-pong HOs, i.e. the HOs forth and back between two cells, but also unwanted HOs directly after the connection setup. The latter case occurs when the cell reselection parameters do not match with the HO parameter settings. The missing HOs on the other hand imply that a UE remains connected with a non-optimal cell, whereas a HO to a better cell would be available.
- HO failure without radio link failure (RLF): These failures are mainly perceived by a degradation in the service. Also, additional signalling traffic is created in the network.
- HO failure with RLF: This is the worst scenario on handover failures. These failures have a combined impact on user experience and on signalling traffic. So, the main objective of MRO is the reduction of HO failures with a RLF.

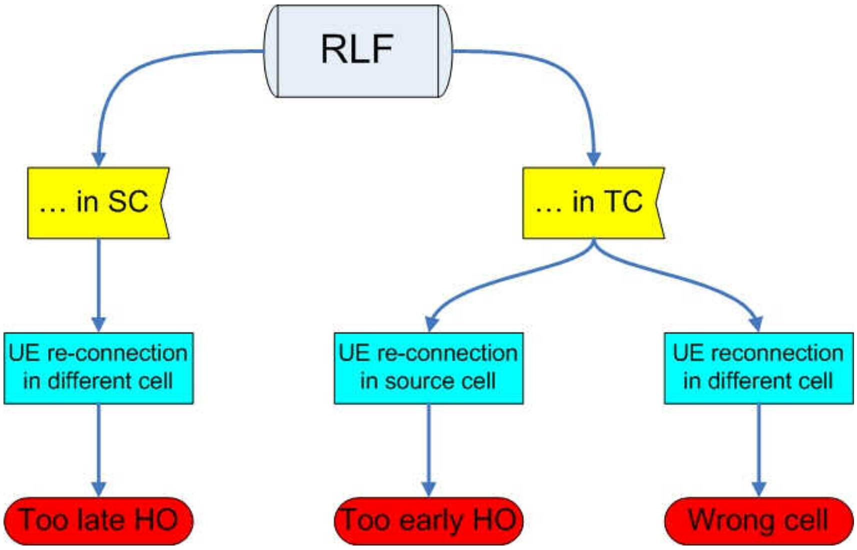


Figure 27: Algorithms to identify the reason of a HO-failure

For an active connection, there are three categories for HO–related failures with RLF which are currently taken into account:

1. Failures due to too late HO triggering
2. Failures due to too early HO triggering
3. Failures due to HO to a wrong cell

The identification of these cases is depicted in Figure 27 and requires an extensive exchange of corresponding control messages between source cell (SC) and target cell (TC), preferably over the X_2 interface. The appropriate architecture to be used here is the distributed architecture. The O&M is mainly involved in restricting the range of the HO parameters, whereas the eNBs select a value within this range.

8.4.2 Mobility Load Balancing Optimization

As in the case of MRO, Mobility Load Balancing (MLB) automatically changes the HO parameters. However, the optimization goal here is the distribution of the cell load to avoid congested cells (Figure 28). However, as this use case operates (at least partially) on the same parameter set as MRO, care must be taken in order to avoid a reduction of the HO reliability. It is also important to take the negotiated QoS into account when transferring a connection to another cell.

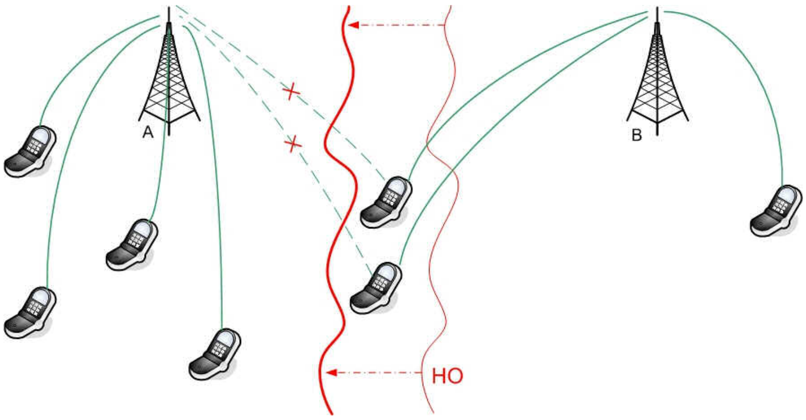


Figure 28: Mobility Load Balancing. The trigger line for handover is moved so that the load is better distributed between the cells.

MRO if defined for inter LTE but also for inter RAT, so the system capacity can be drastically improved by including legacy 3G or 2G networks. Handled in an automatic way, the system can so adapt to time dependent capacity demands.
A necessary ingredient for any load balancing is to spread the load information over the cells of interest, if possible via the X_2 interface, otherwise over the S_1. This contains information about:

- Physical resource block (PRB) occupation of the air interface with detailed information about how many PRBs are used for a guaranteed bit rate.
- Load information of the hardware.
- Transport network layer load information.
- Composite available capacity (UL and DL).

The MLB HO shall be initiated by the source cell, based on the load and capacity information. The corresponding HO preparation shall be distinguishable from conventional HOs in order that the target cell can apply the appropriate admission control .

8.4.3 RACH Optimization

An optimal RACH configuration impacts strongly the system performance. It is a critical factor with respect to call setup delays, data resuming delays from the unsynchronized state, and HO delays, concerning as well the speed as the success rate.

One point is the number of allocated RACH slots. If this number is too small, the probability to get a successful access is reduced by collisions. On the other hand, allocating too many RACH slots is a waste of physical resources, as these slots can not be used by other traffic. Therefore, selecting the optimal number of access slots is of strong importance to the system.
The optimal number depends on the number of users and on the network configuration. With SON these values are varying in time, so the selection of optimal values is time dependent, too.
Apart from the delays, also the UL interference is a critical point. The UE starts its RACH transmission with a preamble. If there is no response the UE again sends a preamble, this time with an increased power. The purpose of this procedure is to access the system with a minimum of power in order to minimize interference. However, if the preamble rejection is not caused by a too weak power but due to congestion, another preamble with a further increased power is transmitted. This obviously enhances the UL interference for the PUSCH, but also for RACH attempts of UEs to a different cell, respectively.

There are 3 classes of parameters which can be optimized:

- RACH configuration: Selection of number and location of the RACH access slots. This is further optimized by a smart choice of the pRACH Configuration Index and the Root Sequence Index.
- RACH preamble splitting and backoff parameter values to avoid congestion.
- RACH transmission power control parameters: The power of the initial preamble and the power ramping on each step. Depending on this choice, different scenarios can be managed in an optimal way. For example, if the range of a cell contains regions with a very large fading difference, a small initial power with a large power ramping may be optimal, whereas in small cells with a more uniform fading a larger initial power together with a smaller power ramping might be the best solution.

The SON entity for the RACH optimization is in the eNB, with the main signalling using either RRC or MAC control. So the main impact is on the air interface protocol stack. However, also the X_2 interface will be concerned in order to be able to exchange access slot configuration between adjacent eNBs for avoiding RACH interferences.

9 Literature

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10 Additional Information

Please send your comments and suggestions regarding this white paper to

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