LTE- Advanced (3GPP Rel.11) 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 commercial networks is strongly increasing around the globe. LTE has become the fastest developing mobile system technology. As other cellular technologies LTE is continuously worked on in terms of improvements. 3GPP groups added technology components into so called releases. Initial enhancements were included in 3GPP Release 9, followed by more significant improvements in 3GPP Release 10, also known as LTE-Advanced. Beyond Release 10 a number of different market terms have been used. However 3GPP reaffirmed that the naming for the technology family and its evolution continues to be covered by the term LTE-Advanced. I.e. LTE-Advanced remains the correct description for specifications defined from Release 10 onwards, including 3GPP Release 12. This white paper summarizes improvements specified in 3GPP Release 11 with focus on the air interface.

White Paper

A. Roessler, M. Kottkamp

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1 Introduction

The LTE (Long Term Evolution) technology was standardized within the 3GPP (3rd Generation Partnership Project) as part of the 3GPP Release 8 feature set. Since end 2009, LTE mobile communication systems are deployed as an evolution of GSM (Global system for mobile communications), UMTS (Universal Mobile Telecommunications System) and CDMA2000, whereas the latter was specified in 3GPP2 (3rd Generation Partnership Project 2). An easy-to-read LTE technology introduction can be found in [1]. The ITU (International Telecommunication Union) coined the term IMT-Advanced to identify mobile systems whose capabilities go beyond those of IMT 2000 (International Mobile Telecommunications). 3GPP responded on IMT-Advanced requirements with a set of additional technology components specified in 3GPP Release 10, also known as LTE-Advanced (see [3] for details). In October 2010 LTE-Advanced (LTE-A) successfully completed the evaluation process in ITU-R complying with or exceeding the IMT-Advanced requirements and thus became an acknowledged 4G technology.

Existing mobile technologies have always been enhanced over a significant time period. As an example, GSM after more than 20 years of operation is still improved. LTE / LTE-A is in its infancy from a commercial operation perspective and one can expect further enhancements for many years to come. This white paper summarizes additional technology components based on LTE, which are included in 3GPP Release 11 specifications.

Each technology component is described in detail in section 2. The technology component dependencies from LTE Release 8 to 11 are illustrated in Fig. 1-1 below.

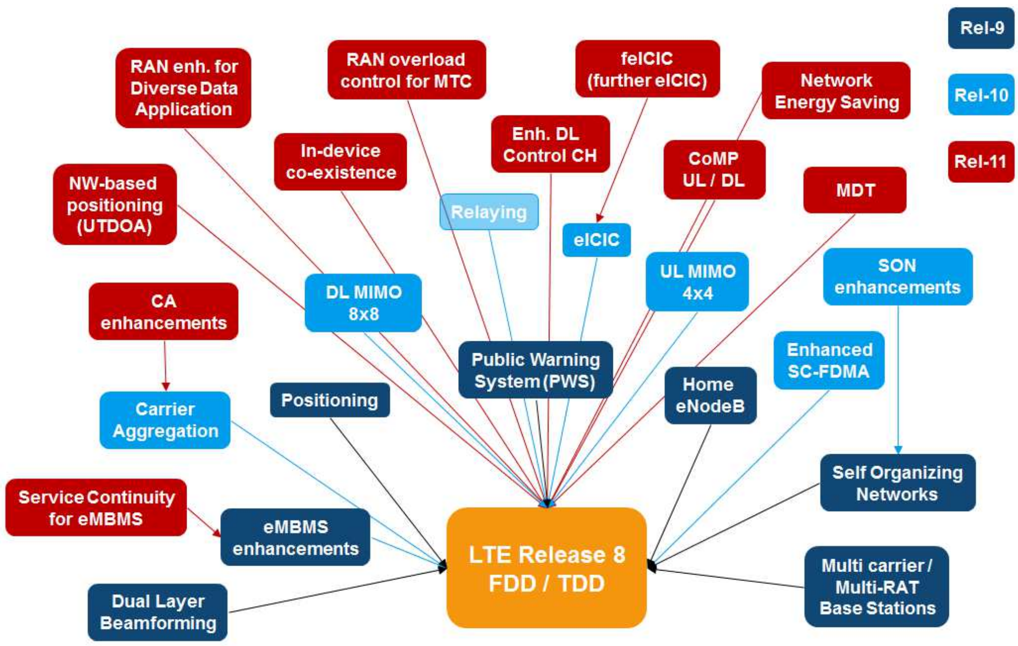

Fig. 1-1: 3GPP Release 8 to 11 technology component dependencies

Section 3 concludes this white paper. Section 4, 5 and 6 provide additional information including a summary of LTE frequency bands and literature references.

2 Technology Components of LTE-Advanced Release 11

Naturally the LTE/LTE-Advanced technology is continuously enhanced by adding either new technology components or by improving existing ones. LTE-Advanced as specified in the 3GPP Release 11 timeframe comprises a number of improvements based on existing features, like LTE carrier aggregation enhancements or further enhanced ICIC. Among the new technology components added, CoMP is clearly the feature with most significant impact for both end user device and radio access network. CoMP was already discussed in the 3GPP Release 10 time frame. However it was finally delayed to 3GPP Release 11. Note that many of the enhancements in 3GPP Release 11 result from the need to more efficiently support heterogeneous network topologies.

2.1 LTE carrier aggregation enhancements

Within the LTE-Advanced feature set of 3GPP Release 10 carrier aggregation was clearly the most demanded feature due to its capability to sum up the likely fragmented spectrum a network operator owns. Naturally further enhancements of this carrier aggregation technology component were introduced in 3GPP Release 11. These are illustrated in the following sections.

2.1.1 Multiple Timing Advances (TAs) for uplink carrier aggregation

As of 3GPP Release 10 multiple carriers in uplink direction were synchronized due to the fact that there was only a single Timing Advance (TA) for all component carriers based on the PCell. The initial uplink transmission timing on the random access channel is determined based on the DL reference timing. The UE autonomously adjusts the timing based on DL timing. This limits the use of UL carrier aggregation to scenarios when the propagation delay for each carrier is equal. However this might be different in cases when repeaters are used on one frequency band only, i.e. in case of inter-band carrier aggregation. Also repeaters/relays may introduce different delays on different frequency bands, if they are band specific.). Another typical scenario might be a macro cell covering a wide area aggregated with a smaller cell at another frequency for high data throughput. The geographical location of the antennas for the two cells may be different and thus a difference in time delay may occur. Additionally and potentially even more important, if UL carrier aggregation is used in combination with UL CoMP (see section 2.2), the eNodeB receiving entities may be located at different places, which also requires individual timing advance for each component carrier (see Fig. 2-1).

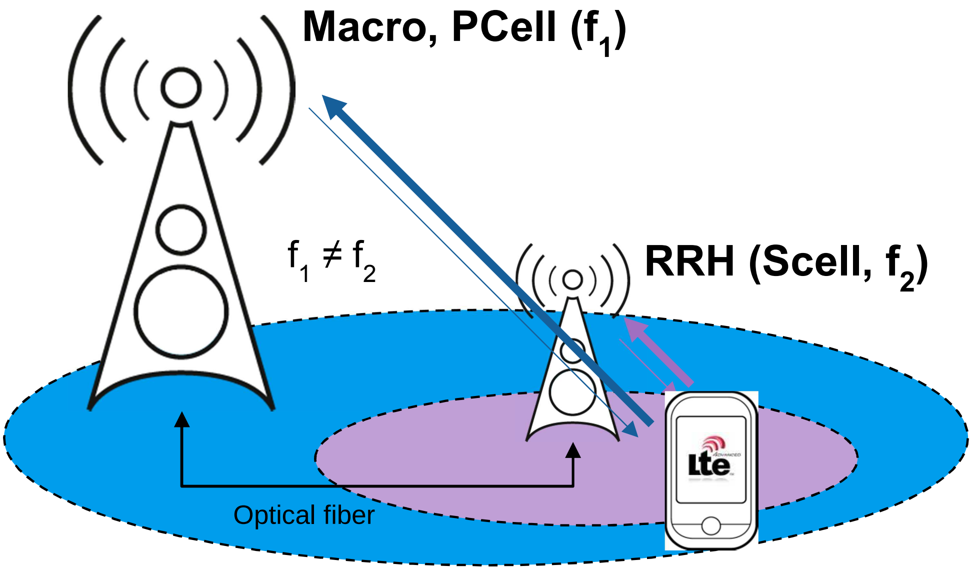

Fig. 2-1: CoMP scenario 3 requires different timing advance if multiple carriers are used in UL

To enable multiple timing advances in 3GPP Release 11, the term Timing Advance Group (TAG) was introduced [4]. A TAG includes one or more serving cells with the same UL timing advance and the same DL timing reference cell. If a TAG contains the PCell, it is named as Primary Timing Advance Group (pTAG). If a TAG contains only SCell(s), it is named as Secondary Timing Advance Group (sTAG). From RF (3GPP RAN4) perspective in 3GPP Release 11 carrier aggregation is limited to a maximum of two downlink carriers. In consequence only two TAGs are allowed. The initial UL time alignment of sTAG is obtained by an eNB initiated random access procedure the same way as establishing the initial timing advance for a single carrier in 3GPP Release 8. The SCell in a sTAG can be configured with RACH resources and the eNB requests RACH access on the SCell to determine timing advance. I.e. the eNodeB initiates the RACH transmission on the secondary cells by a PDCCH order send on the primary cell. The message in response to a SCell preamble is transmitted on the PCell using RA-RNTI that conforms to 3GPP Release 8. The UE will then track the downlink frame timing change of the SCell and adjust UL transmission timing following the timing advance commands from the eNB. In order to allow multiple timing advance commands, the relevant MAC timing advance command control element has been modified. The control element consists of a new 2 bit Timing Advance Group Identity (TAG Id) and a 6 bit timing advance command field (unchanged compared to 3GPP Release 8) as shown in Fig. 2-2. The Timing Advance Group containing the PCell has the Timing Advance Group Identity 0.

TAG Id	Timing Advance Command	Oct 1

Fig. 2-2: Timing Advance Command MAC control element [10]

As of 3GPP Release 8 the timing changes are applied relative to the current uplink timing as multiples of 16 T_S. The same performance requirements of the timing advance maintenance of the pTAG are also applicable to the timing advance maintenance of the sTAG.

2.1.2 Non-contiguous intra-band carrier aggregation

Carrier aggregation as of 3GPP Release 10 enables intra-band and inter-band combinations of multiple carrier frequencies. In the intra-band case the carrier frequencies may or may not be adjacent, therefore both continuous and non-contiguous carrier aggregation is possible. See Fig. 2-3 for the naming convention as specified in [12].

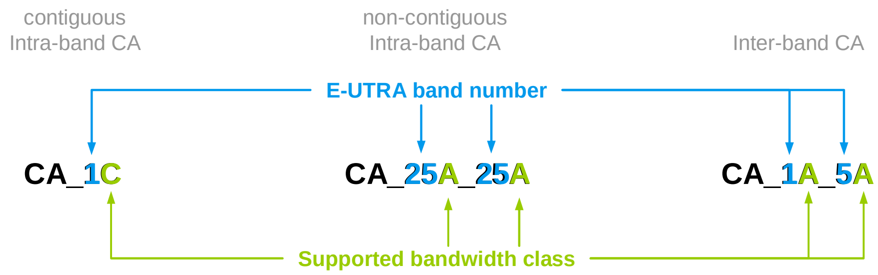

Fig. 2-3: ***Notation of carrier aggregation support (type, frequency band, and bandwidth)***

However from 3GPP RAN4 perspective the non-contiguous carrier aggregation case was not fully completed in 3GPP Release 10 time frame. Consequently missing requirements were added in 3GPP Release 11. These include modifications and clarification of the ACLR, ACS and unwanted emission requirements and more significantly the addition of base station Cumulative ACLR (CACLR) and timing alignment error requirements. Fig. 2-4 provides the basic terms and definitions for non-contiguous intra-band carrier aggregation.

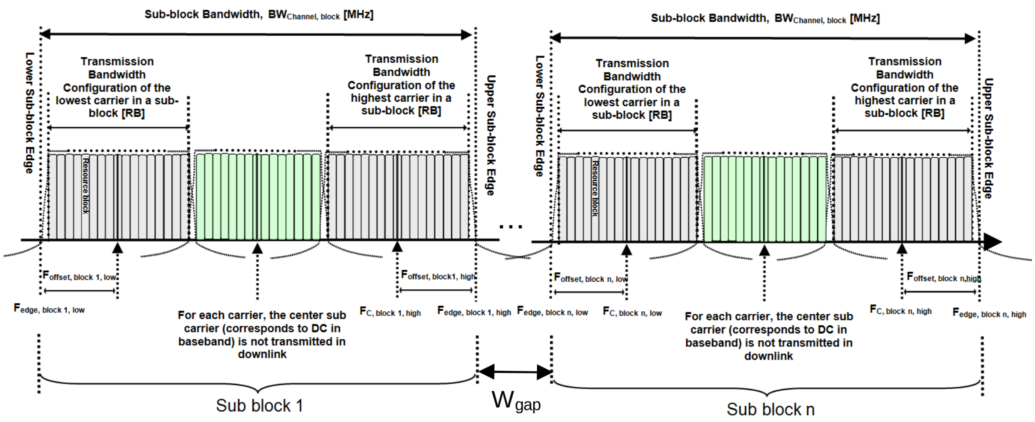

Fig. 2-4: Non-contiguous intra-band CA terms and definitions [12]

The following sections describe the modifications for both the user equipment and the base station. Note that generally up to five carriers may be aggregated in LTE-Advanced. However 3GPP RAN4 has limited the definition of core and performance requirements to the most realistic scenario of two DL carrier frequencies in combination with one UL carrier frequency.

2.1.2.1 Modification and addition of base station requirements

Frames of the LTE signals present at the base station antenna port(s) are not perfectly aligned in time. For operation in case of MIMO, TX diversity and/or multiple carrier frequencies, the timing error between a specific set of transmitters needs to fulfill specified requirements. For the non-contiguous carrier aggregation case, the TAE requirement highlighted in blue was added.

- For MIMO or TX diversity transmissions, at each carrier frequency, TAE shall not exceed 65 ns.
- For intra-band contiguous carrier aggregation, with or without MIMO or TX diversity, TAE shall not exceed 130 ns.
- **For intra-band non-contiguous carrier aggregation, with or without MIMO or TX diversity, TAE shall not exceed 260 ns.**
- For inter-band carrier aggregation, with or without MIMO or TX diversity, TAE shall not exceed 1.3 µs.

With respect to ACLR a new so-called Cumulative Adjacent Channel Leakage power Ratio (CACLR) requirement was introduced. The CACLR in a sub-block gap is the ratio of:

- the sum of the filtered mean power centred on the assigned channel frequencies for the two carriers adjacent to each side of the sub-block gap, and
- the filtered mean power centred on a frequency channel adjacent to one of the respective sub-block edges.

New CACLR limits for use in paired and unpaired spectrum are specified according to Table 2-1 and Table 2-2 below.

Table 2-1: Base Station CACLR in non-contiguous paired spectrum

Sub-block gap size (W_{gap}) where the limit applies	BS adjacent channel centre frequency offset below or above the sub-block edge (inside the gap)	Assumed adjacent channel carrier (informative)	Filter on the adjacent channel frequency and corresponding filter bandwidth	ACLR limit
5 MHz ≤ W_{gap} < 15 MHz	2.5 MHz	3.84 Mcps UTRA	RRC (3.84 Mcps)	45 dB
10 MHz < W_{gap} < 20 MHz	7.5 MHz	3.84 Mcps UTRA	RRC (3.84 Mcps)	45 dB

Table 2-2: Base Station CACLR in non-contiguous unpaired spectrum

Sub-block gap size (W_{gap}) where the limit applies	BS adjacent channel centre frequency offset below or above the sub-block edge (inside the gap)	Assumed adjacent channel carrier (informative)	Filter on the adjacent channel frequency and corresponding filter bandwidth	ACLR limit
5 MHz ≤ Wgap < 15 MHz	2.5 MHz	5MHz E-UTRA carrier	Square (BW_{Config})	45 dB
10 MHz < Wgap < 20 MHz	7.5 MHz	5MHz E-UTRA carrier	Square (BW_{Config})	45 dB

Additionally the applicability of the existing ACLR requirements assuming UTRA and EUTRA operation on adjacent carriers is clarified. If the frequency gap between the non-contiguous carriers is less than 15 MHz, no ACLR requirement applies. For frequency gaps larger than 15 MHz ACLR applies for the first adjacent channel and for frequency gaps larger than 20 MHz the ACLR requirement for the second adjacent channel applies.

Additionally clarifications for various transmitter and receiver requirements were incorporated (see [13] for details).

- Operating band unwanted emissions apply inside any sub-block gap.
- Transmit intermodulation requirements are applicable inside a sub-block gap for interfering signal offsets where the interfering signal falls completely within the sub-block gap. In this case the interfering signal offset is defined relative to the sub-block edges.
- Receiver ACS, blocking and intermodulation requirements apply additionally inside any sub-block gap, in case the sub-block gap size is at least as wide as the E-UTRA interfering signal.

2.1.2.2 Modification and addition of UE requirements

With respect to the user equipment only 5 MHz and 10 MHz bandwidths have to be supported for intra-band non-contiguous carrier aggregation. The corrections / modifications in 3GPP Release 11 naturally refer to the reception of a non-contiguous carrier aggregation signal. 3GPP RAN4 added so-called in-gap and out-of-gap tests. In-gap test refers to the case when the interfering signal(s) is (are) located at a negative offset with respect to the assigned channel frequency of the highest carrier frequency; or located at a positive offset with respect to the assigned channel frequency of the lowest carrier frequency. Out-of-gap test refers to the case when the interfering signal(s) is (are) located at a positive offset with respect to the assigned channel frequency of the highest carrier frequency, or located at a negative offset with respect to the assigned channel frequency of the lowest carrier frequency.

Details of the modified requirements are specified in [12]. Mainly affected are maximum input level (-22dBm for the sum of both received carriers at same power), adjacent channel selectivity, out-of band and in-band blocking, spurious response and receiver intermodulation requirements. However ACS requirements, in-band blocking requirements and narrow band blocking requirements need only to be supported for in-gap test, if the frequency gap between both carriers fulfills the following condition:

$$W_{gap} \geq \text{(Interferer frequency offset 1)} + \text{(Interferer frequency offset 2)} - 0.5 * (\text{(Channel bandwidth 1)} + \text{(Channel bandwidth 2)})$$

With respect to reference sensitivity performance new requirements were added addressing both 5 MHz (25 RB) and 10 MHz (50 RB) bandwidth cases. The throughput of each downlink component carrier needs to be at least 95% of the maximum throughput of the reference measurement channels. This reference sensitivity is defined to be met with both downlink component carriers active and one uplink carrier active. Table 2-3 shows the configuration for this additional receiver requirement.

Table 2-3: Intra-band non-contiguous CA uplink configuration for reference sensitivity

CA configuration	Aggregated channel bandwidth (PCC+SCC)	W_{gap} / [MHz]	PCC allocation	ΔRIBNC (dB)	Duplex mode
CA_25A-25A	25RB + 25RB	$30.0 < W_{gap} \leq 55.0$	10[1]	5.0	FDD
		$0.0 < W_{gap} \leq 30.0$	25[1]	0.0	
	25RB + 50RB	$25.0 < W_{gap} \leq 50.0$	10[1]	4.5	
		$0.0 < W_{gap} \leq 25.0$	25[1]	0.0	
	50RB + 25RB	$15.0 < W_{gap} \leq 50.0$	10[4]	5.5	
		$0.0 < W_{gap} \leq 15.0$	32[1]	0.0	
	50RB + 50RB	$10.0 < W_{gap} \leq 45.0$	10[4]	5.0	
		$0.0 < W_{gap} \leq 10.0$	32[1]	0.0	
NOTE 1: [1] refers to the UL resource blocks shall be located as close as possible to the downlink operating band but confined within the transmission. NOTE 2: W_{gap} is the sub-block gap between the two sub-blocks. NOTE 3: The carrier center frequency of PCC in the UL operating band is configured closer to the DL operating band. NOTE 4: [4] refers to the UL resource blocks shall be located at RB_{start}=33.					

2.1.3 Additional Special Subframe Configuration for LTE TDD and support of different UL/DL configurations on different bands

As of 3GPP Release 10 when TDD carrier aggregation is applied, all carrier frequencies use the same UL/DL configuration. This restriction is removed in 3GPP Release 11, i.e. the different carriers may use different UL/DL ratios out of the existing configurations as shown in Table 2-4. This mainly impacts the HARQ-ACK reporting procedure (see details specified in section 7.3.2.2 in [7]).

Table 2-4: Uplink-downlink configurations

UL / DL configuration	DL to UL switch-point periodicity	Subframe number									
		0	1	2	3	4	5	6	7	8	9
0	5 ms	D	S	U	U	U	D	S	U	U	U
1	5 ms	D	S	U	U	D	D	S	U	U	D
2	5 ms	D	S	U	D	D	D	S	U	D	D
3	10 ms	D	S	U	U	U	D	D	D	D	D
4	10 ms	D	S	U	U	D	D	D	D	D	D
5	10 ms	D	S	U	D	D	D	D	D	D	D
6	5 ms	D	S	U	U	U	D	S	U	U	D

Furthermore two additional special subframe configurations have been added (see Table 2-5 and Table 2-6).

- Special Subframe configuration 9 with normal cyclic prefix in downlink
- Special Subframe configuration 7 with extended cyclic prefix in downlink

Table 2-5: Configuration of special subframe for normal CP (lengths of DwPTS/GP/UpPTS)

Special subframe configuration	Normal cyclic prefix					
	DwPTS [ms]	GP [ms]	UpPTS [ms]	DwPTS [symbols]	GP [symbols]	UpPTS [symbols]
0	0.2142	0.7146		3	10	
1	0.6422	0.2866		9	4	
2	0.7134	0.2154	0.0712	10	3	1
3	0.7847	0.1441		11	2	
4	0.8559	0.0729		12	1	
5	0.2142	0.6433		3	9	
6	0.6422	0.2153		9	3	
7	0.7134	0.1441	0.1425	10	2	2
8	0.7847	0.0728		11	1	
9	0.4280	0.4295		6	6	

Table 2-6: Configuration of special subframe for extended CP (lengths of DwPTS/GP/UpPTS)

Special subframe configuration	Extended cyclic prefix					
	DwPTS [ms]	GP [ms]	UpPTS [ms]	DwPTS [symbols]	GP [symbols]	UpPTS [symbols]
0	0.25	0.6667		3	8	
1	0.6667	0.25	0.0833	8	3	1
2	0.75	0.1667		9	2	
3	0.8333	0,0833		10	1	
4	0.25	0.6667		3	7	
5	0.6667	0.25	0.1666	8	2	2
6	0.75	0.1667		9	1	
7	0.4167	0.4167		5	5	
8	-	-	-	-	-	-
9	-	-	-	-	-	-

The additions allow a balanced use of DwPTS and GP, i.e. enhance the system flexibility while maintaining the compatibility with TD-SCDMA.

2.1.4 Enhanced TxD schemes for PUCCH format 1b with channel selection

Although generally two antennas are available at the end user device side, up to 3GPP Release 10 these are only used for receiving data. With 3GPP Release 11 it is possible to apply transmit diversity in uplink direction using both antennas also to transmit. Although not named in 3GPP specifications the basic scheme used is Spatial Orthogonal-Resource Transmit Diversity (SORTD). Note that 3GPP RAN1 discussed the applicability of this technology component. It was finally decided that the transmit diversity can only be used if the UE is carrier aggregation capable (TDD) or configured with more than one cell, i.e. operating in carrier aggregation mode (FDD).

The principle of SORTD is to transmit the uplink control signaling using different resources (time, frequency, and/or code) on the different antennas. In essence, the PUCCH transmissions from the two antennas will be identical to PUCCH transmissions from two different terminals using different resources. Thus, SORTD creates additional diversity but achieves this by using twice as many PUCCH resources, compared to non-SORTD transmission. The modulated symbol is duplicated into each antenna port in order to perform CDM/FDM spreading operation. The signals are transmitted in a space-resource orthogonal manner. PUCCH format 1b with channel selection is possible for both FDD and TDD modes (see for [7] details).

2.2 Coordinated Multi-Point Operation for LTE (CoMP)

CoMP, short for Coordinated Multi-Point Operation for LTE, is one of the most important technical improvements coming with 3GPP Release 11 with respect to the new Heterogonous Network (HetNet) deployment strategies, but also for the traditional homogenous network topology. In brief HetNet's aim to improve spectral efficiency per unit area using a mixture of macro-, pico-, femto-cell base station and further relays. In contrast homogenous network topologies comprise only one cell size, usually the macro layer. Nevertheless with both network deployment strategies mainly cell edge users are experiencing so called inter-cell interference. This interference occurs due to the individually performed downlink transmission and uplink reception on a per cell basis. The goal with CoMP is to further minimize inter-cell interference for cells that are operating on the same frequency which is becoming even more severe with Heterogonous Network deployments targeted by many network operators worldwide.

As the name implies, CoMP shall allow the optimization of transmission and reception from multiple distribution points, which could be either multiple cells or Remote Radio Heads (RRH), in a coordinated way. CoMP will enable joint transmission and/or reception to mobile device, allow the devices to select the closest base station and will affect power consumption as well as overall throughput and thus system capacity. It further allows load balancing and therefore contributes to the mitigation of inter-cell interference.

3GPP standardization is based on four different CoMP scenarios. The first two scenarios both focusing on homogenous network deployment, ones with a single eNode B serving multiple sectors (Scenario 1) and second with multiple high-transmit power RRH (Scenario 2); see Fig. 2-5.

The remaining two scenarios target HetNets, where macro cells and small(er) cells are jointly deployed using different cell identities (ID; Scenario 3) or the same cell ID (Scenario 4).

Due to its complexity CoMP has been separated during the standardization process into two independent work items for Downlink and Uplink, which are explained in the following sections. Both link directions benefit from the two major schemes being used in CoMP: Joint Processing (JP), which includes Joint Transmission (JT; Downlink) and Joint Reception (JR; Uplink) as well as Coordinated Scheduling / Beamforming.

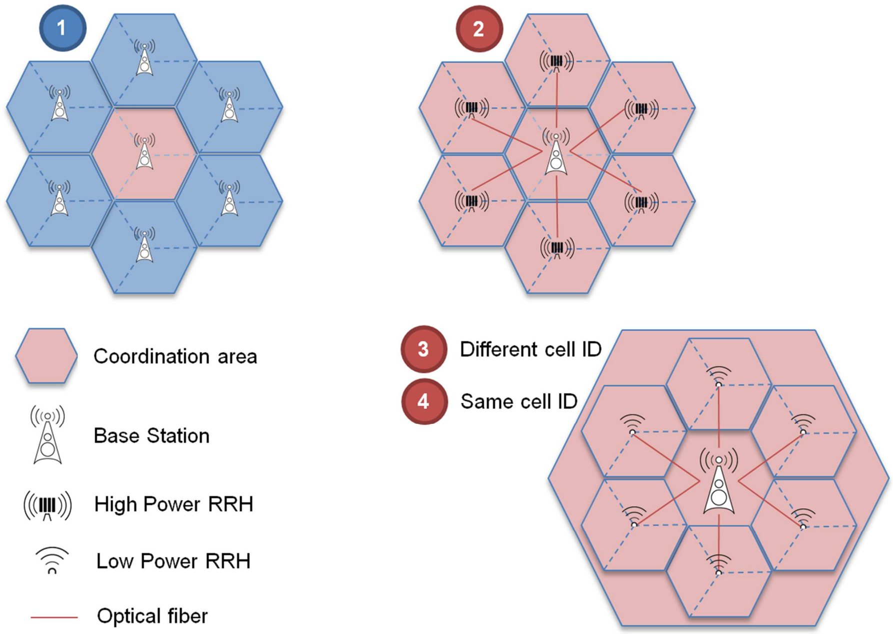

Fig. 2-5: Coordinated Multi-Point Operation (CoMP) scenarios

2.2.1 CoMP terminology

To understand the details behind Downlink and Uplink CoMP understanding the terminology is a pre-requisite. There are CoMP cooperating set, CoMP measurement set and CoMP resource management. What's behind?

CoMP Cooperating Set. The CoMP Cooperating Set is determined by higher layers. It is a set of geographically separated distribution points that are directly or indirectly involved in data transmission to a device in a time-frequency resource. Within a cooperating set, there are CoMP points. In terms of CoMP technique (see below), this could be multiple points at each subframe (e.g. Joint Transmission) or a single point at each subframe (e.g. Coordinated Scheduling / Beamforming).

CoMP Measurement Set. The CoMP Measurement Set is a set of points, about which channel state information (CSI) or statistical data related to their link to the mobile device is measured and / or reported. This set is well determined by higher layers. A mobile device, is enabled to down-select the points for which the actual feedback is reported.

CoMP resource management. The CoMP resource management is a set of CSI Reference Signals (CSI-RS) resources, for which CSI-RS based RSRP[1] measurements can be made and reported.

Fig. 2-6 and Fig. 2-7 are showing the definition of CoMP Cooperating Set and the CoMP Measurement Set for the two defined cases: all cells are using different physical cell identities and where the cells are having the same cell identity. For the latter the

[1] **RSRP – Reference Signal Received Power**; see 3GPP TS 36.214 Physical Layer measurements, Rel-11

concept of virtual cell identities can be applied. Virtual cell identifies are assigned by higher layer.

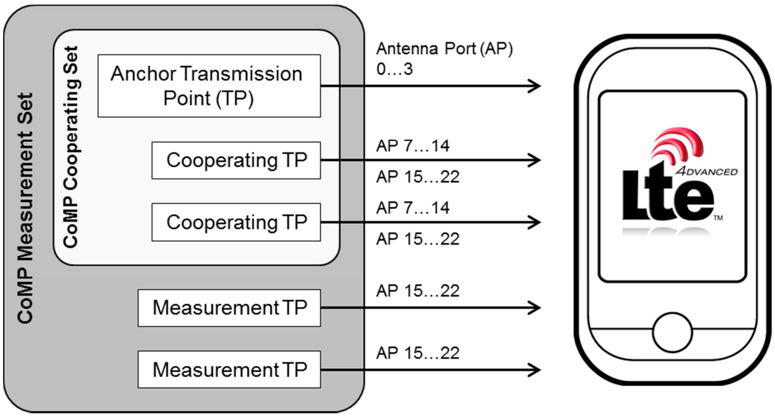

Fig. 2-6: Downlink CoMP Cooperating and Measurement set for cells using the *same* cell identity.

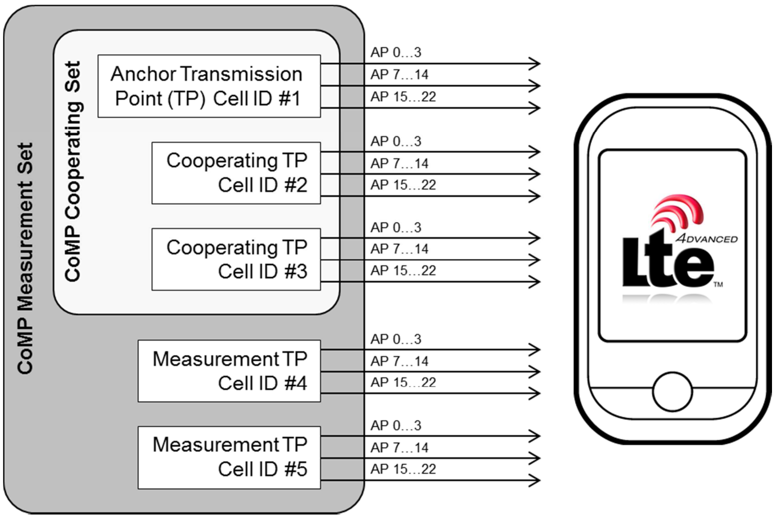

Fig. 2-7: Downlink CoMP Cooperating and Measurement Set for cells using *different* cell identities.

2.2.2 Downlink CoMP

Fig. 2-8 gives an overview of the CoMP schemes used in the downlink. Joint Transmission (JT) enables simultaneous data transmission from multiple points to a single or even multiple UE's. That means the UE's data is available at multiple points, belonging to the CoMP cooperating set, throughout the network. The goal is to increase signal quality at the receiver and thus the average throughput.

Coherent JT means the RRH are coordinated by the corresponding eNode B and are transmitting the data time-synchronized. Non-Coherent JT is associated with a non-synchronous transmission. In general JT requires a low latency between the transmission points, high-bandwidth backhaul and low mobility UE's.

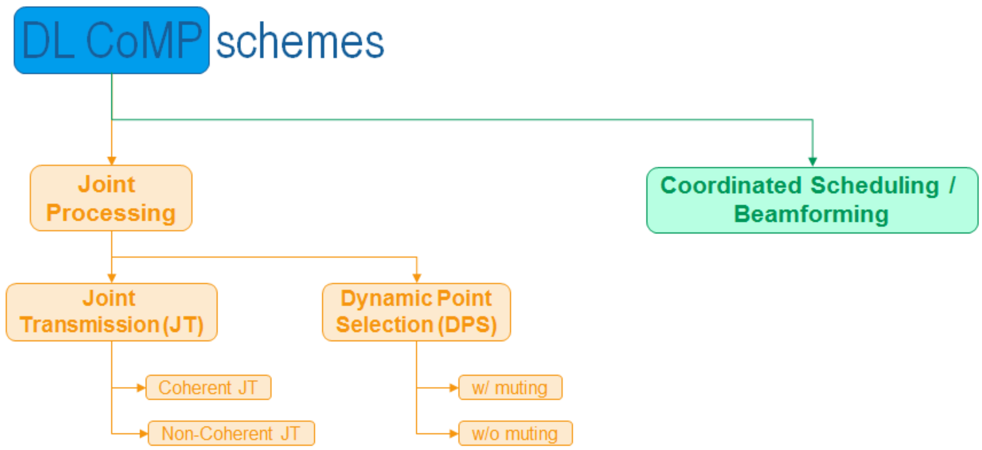

Fig. 2-8: Overview Downlink CoMP schemes

Also for Dynamic Point Selection (DPS) the PDSCH data has to be available at multiple points. However in contrast to JT, data is only transmitted from one point at any given time to reduce interference.

For Coordinated Scheduling / Beamforming (CBS) the data is still only present at one transmission point. However, with the coordination of frequency allocations and used precoding schemes (beamforming) at the various transmission points, performance can be increased and interference can be mitigated. Fig. 2-9 shows an example for CBS, where two femto cells (Home eNB) are using coordinated beamforming vectors by serving two devices (UE1 and UE2) while reducing interference.

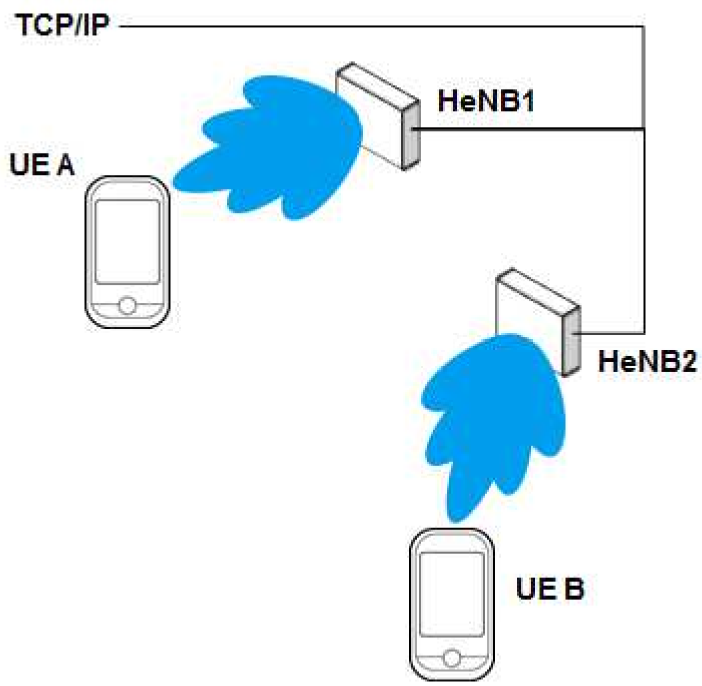

Fig. 2-9: Example of Coordinated Scheduling / Beamforming (CBS) with two femto cells

2.2.3 Uplink CoMP

Fig. 2-10 shows the CoMP schemes being utilized for the uplink. For Joint Reception the PUSCH transmitted by the UE is received jointly at multiple points (part of or entire CoMP cooperating set) at a time to improve the received signal quality. With regards to Coordinated Scheduling and Beamforming in the uplink the scheduling and precoding selection decisions are made with coordination among points corresponding to the CoMP cooperating set. But the PUSCH data is intended for one point only.

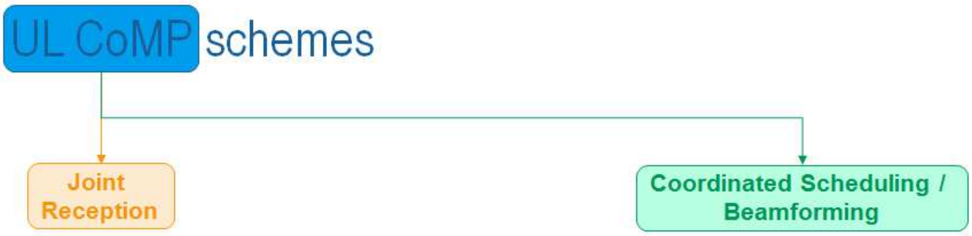

Fig. 2-10: Uplink CoMP schemes

A fundamental change due to CoMP in the LTE uplink is the introduction of virtual cell ID's. As of 3GPP Release 8 the generation of the Demodulation Reference Signal (DMRS) embedded in two defined SC-FDMA symbols in an uplink subframe is dependent on the physical cell identity (PCI). The PCI is derived from the downlink. For future HetNet deployment scenarios, where a macro cell provides the coverage and several small cells are used for capacity, there is higher uplink interference at the cell boundaries. This is especially true for the case, that macro cell and small cells are using the same cell identities. Due to this the concept virtual cell identities (VCID) is introduced with CoMP in 3GPP Release 11.

Due to VCID reception point and transmission point are not necessarily the same anymore. Based on the interference scenario, a device might receive its downlink from the macro cell, where the uplink is received by a small cell; see Fig. 2-11.

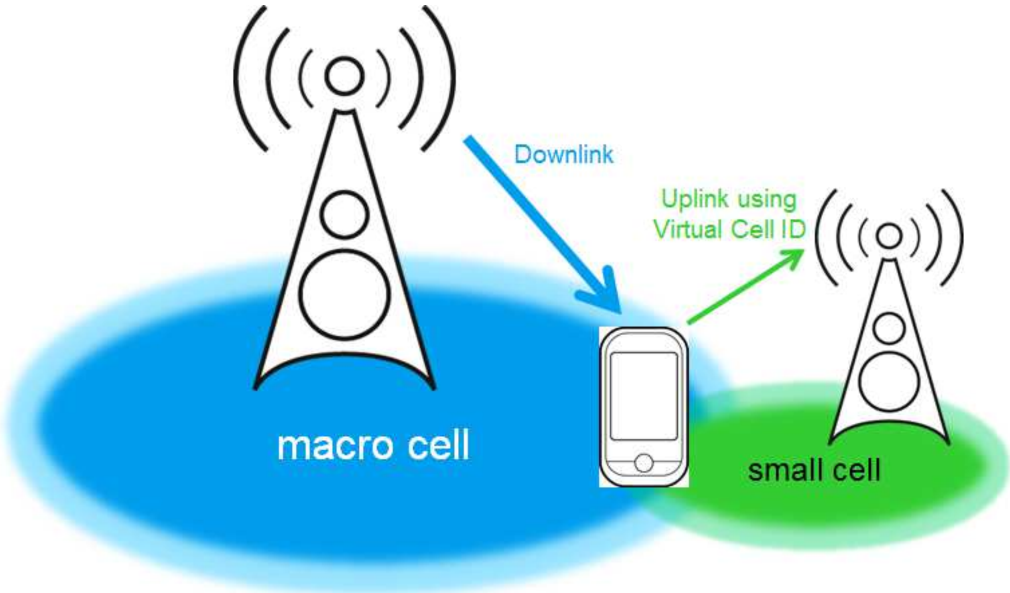

Fig. 2-11: Virtual Cell ID for Uplink CoMP

2.3 E-PDCCH: new control channel in 3GPP Release 11 for LTE-Advanced

2.3.1 Why a new control channel in LTE?

One of the major enhancements in 3GPP Release 11 is the introduction of a new downlink control channel, the Enhanced Physical Downlink Control Channel (E-PDCCH). The standardization of the E-PDCCH was necessary to support new features like CoMP, downlink MIMO and the considered introduction of a new carrier type with 3GPP Release 12 all with the intention to support the following goals:

- Support of increased control channel capacity.
- Support of frequency-domain ICIC.
- Achieve improved spatial reuse of control channel resources.
- Support beamforming and/or diversity.
- Operate on a new carrier type and in MBSFN subframes.
- Coexist on the same carrier as legacy Rel-8 and Rel-10 devices.

2.3.2 Enhanced PDCCH (E-PDCCH) design and architecture

Based on the requirements the E-PDCCH uses a similar design to the one of the Physical Data Shared Channel (PDSCH). Instead of using first symbols of a subframe, where the Downlink Control Information (DCI) is spread over the entire bandwidth, the E-PDCCH uses the same resources as the PDSCH; see Fig. 2-12.

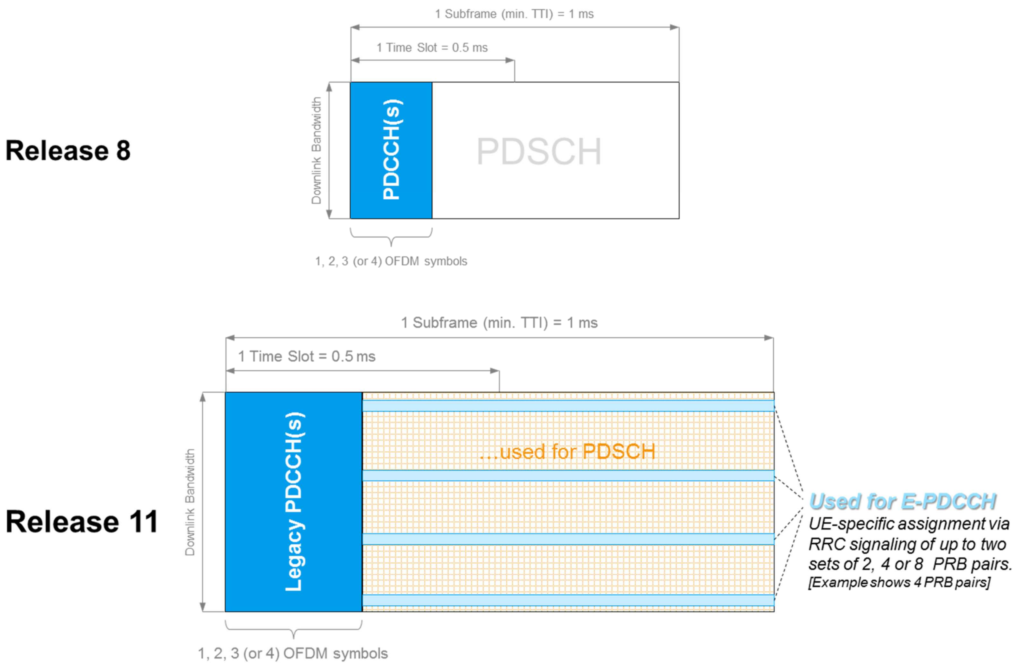

Fig. 2-12: PDCCH (Rel-8) versus E-PDCCH (Rel-11)

Dedicated RRC signaling will indicate to the device, which subframes it has to monitor for the E-PDCCH. The UE will also be informed, if it has to monitor one or two sets of Resource Blocks (RB) pairs. These RB pairs could be of size 2, 4 or 8 RBs and carry the E-PDCCH, which could be either localized or distributed transmission. Each RB pair consist now of a number of Enhanced Control Channel Elements (ECCE). Each E-PDCCH uses one or more ECCE, where an ECCE consist out of 4 or 8 Enhanced Resource Element Groups, short EREG. There are 16 EREGs per RB pair, where 9 Resource Elements (RE) form an EREG for normal cyclic prefix usage; see Fig. 2-13, where DM-RS stands for Demodulation Reference Signals.

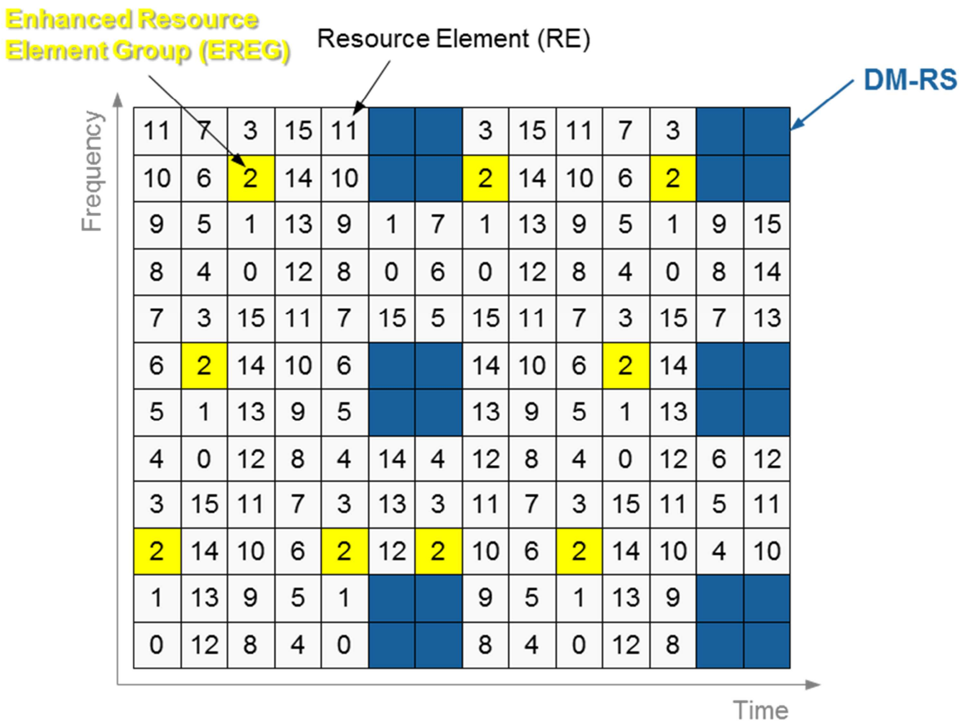

Fig. 2-13: Enhanced Resource Element Group (EREG) for E-PDCCH

Now EREG can be further organized in so called EREG groups. EREG group #0 is formed by EREG with indices 0, 4, 8 and 12, where EREG group #1 is formed by indices 1, 5, 9 and 13 and so on. In total there are four EREG groups, where Fig. 2-14 shows EREG group #3.

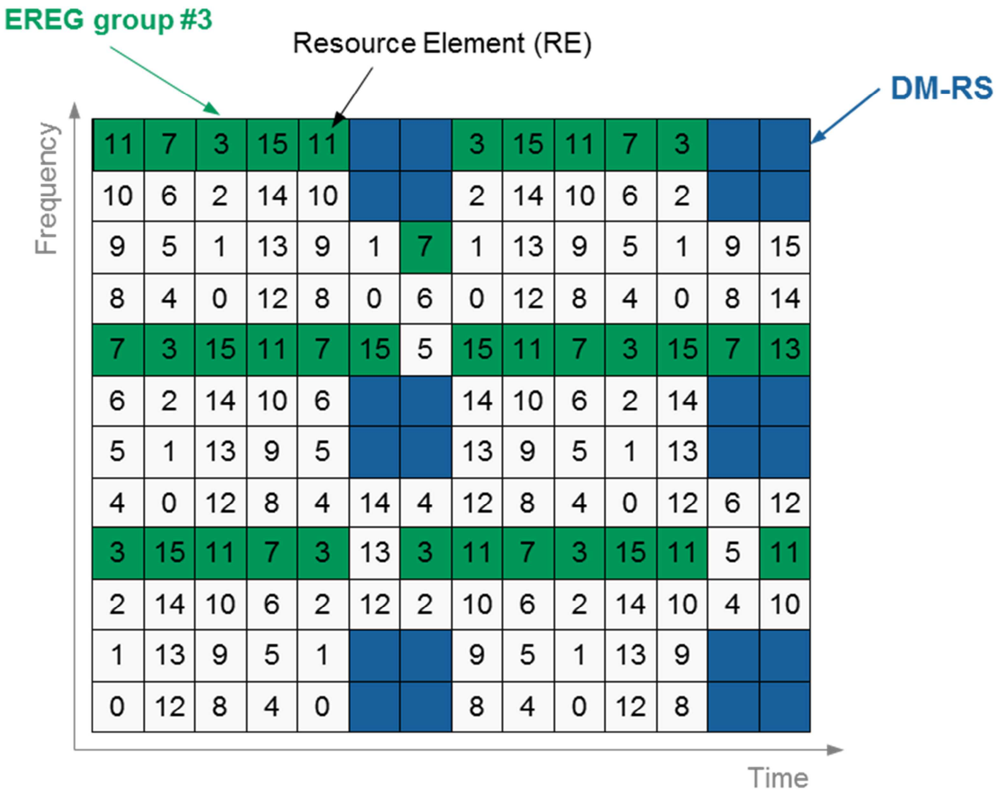

Fig. 2-14: EREG group #3

As explained earlier an ECCE can consist of four or eight EREG. In case of four EREG one EREG group forms an ECCE, in case of eight EREG, groups #0 and #2 form one part of the ECCE, where EREG groups #1 and #3 form the other portion of the ECCE.

The grouping has an impact to the transmission type used for the E-PDCCH. For localized transmission the EREG group is located within a single RB pair. This allows frequency-selective scheduling, using favorable sub-bands based on radio channel feedback gained by the device. In case channel feedback is not reliable, then the E-PDCCH can be transmitted using distributed transmission mode, where it exploits additional frequency diversity.

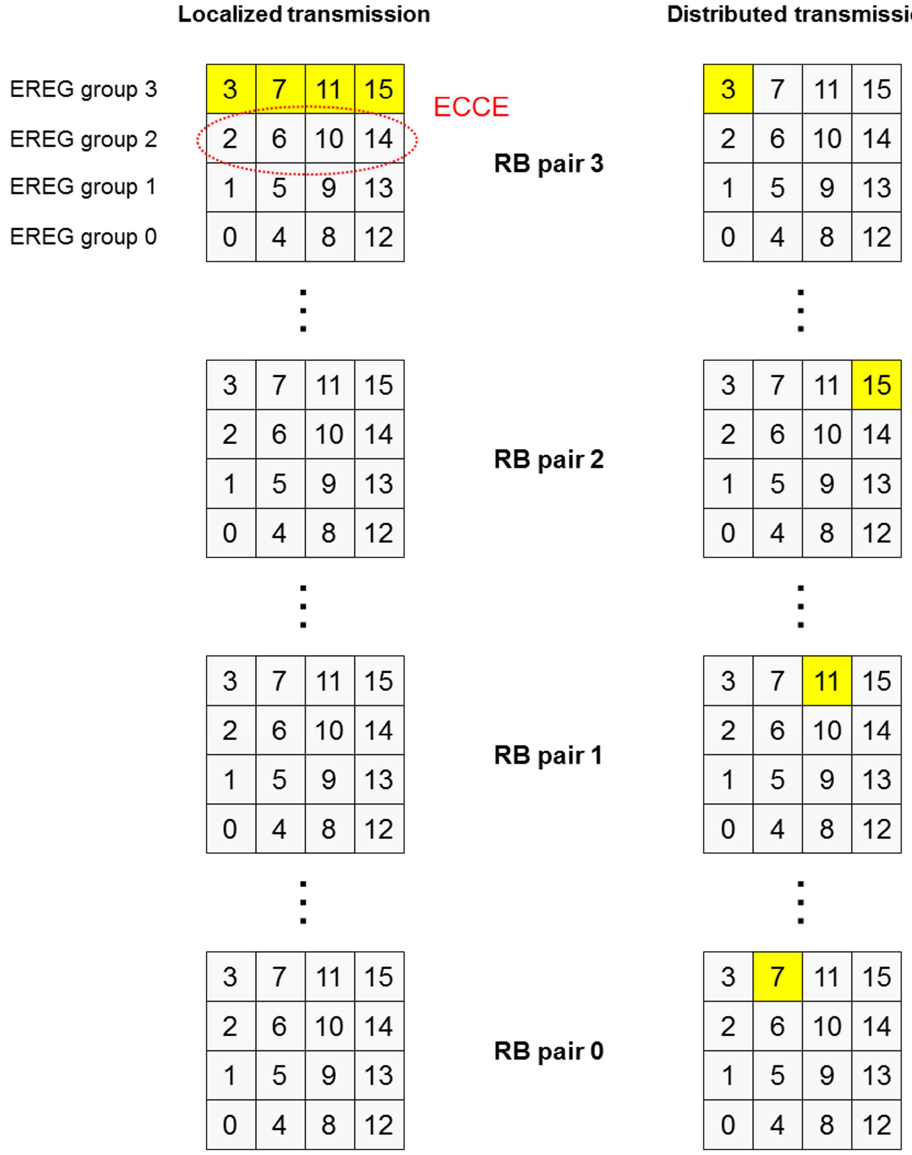

Fig. 2-15: E-PDCCH – Localized versus Distributed Transmission

2.4 Further enhanced non CA-based ICIC (feICIC)

Generally inter-cell interference coordination (ICIC) has the task to manage radio resources such that inter-cell interference is kept under control. Up to 3GPP Release 10 the ICIC mechanism includes a frequency and time domain component. ICIC is inherently a multi-cell radio resource management function that needs to take into account information (e.g. the resource usage status and traffic load situation) from multiple cells. The frequency domain ICIC manages radio resource, notably the radio resource blocks, such that multiple cells coordinate use of frequency domain resources. The capability to exchange related information on the X2 interface between eNodeBs is available since 3GPP Release 8. For the time domain ICIC, subframe utilization across different cells are coordinated in time through so called Almost Blank Subframe (ABS) patterns. This capability was added in 3GPP Release 10 (see [3] for details).

The main enhancement in 3GPP Release 11 was to provide the UE with Cell specific Reference Symbol (CRS) assistance information of the aggressor cells in order to aid the UE to mitigate this interference. In order to define proper CRS-based measurements and improve demodulation for time domain ICIC with large bias (e.g. 9 dB), it was necessary to define signaling support indicating which neighbor cells have ABS configured.

The information element RadioResourceConfigDedicated ([11]) is generally used to setup/modify/release RBs, to modify the MAC main configuration, to modify the SPS configuration and to modify dedicated physical configuration. With 3GPP Release 11, this information element may optionally include a neighCellsCRSInfo field. neighCellsCRSInfo includes the following information of the aggressor cell(s):

- Physical Cell ID.
- Number of used antenna ports (1, 2, 4).
- MBMS subframe configuration.

Furthermore in case of strong interference the UE may not be able to decode important system information transmitted. Therefore as of 3GPP Release 11 it became possible to transmit System Information Block Type 1 (SIB1) information, which is usually provided on the PDSCH with a periodicity of 80 ms, via dedicated RRC signaling. SIB1 includes important information like PLMN IDs, tracking area code, cell identity, access restrictions, and information on scheduling of all other system information elements. From 3GPP Release 11 this information may be optionally included in the RRCConnectionReconfiguration message. If the UE receives the SIB1 via dedicated RRC signaling it needs to perform the same actions as upon SIB1 reception via broadcast.

Note that additional measurement reporting requirements under time domain measurement resource restrictions with CRS assistance data have been included in [14].

2.5 Network Based Positioning

Positioning support was added to the LTE technology within 3GPP Release 9. Those additions included the following positioning methods (see [2] for a detailed description)

- network-assisted GNSS
- downlink positioning
- enhanced cell ID

Within 3GPP Release 11 support for uplink positioning was added. The uplink (e.g. Uplink Time Difference of Arrival (UTDOA)) positioning method makes use of the measured timing at multiple reception points of UE signals. The method uses time difference measurements based on Sounding Reference Signal (SRS), taken by several base stations, to determine the UE’s exact location. For that purpose Location Measurement Units (LMU’s) are installed at base stations. Fig. 2-16 provides the principle architecture and the main interfaces relevant for LTE positioning. The new LMU and the new SLm interface are marked in red. Note that uplink positioning methods have no impact on the UE implementation.

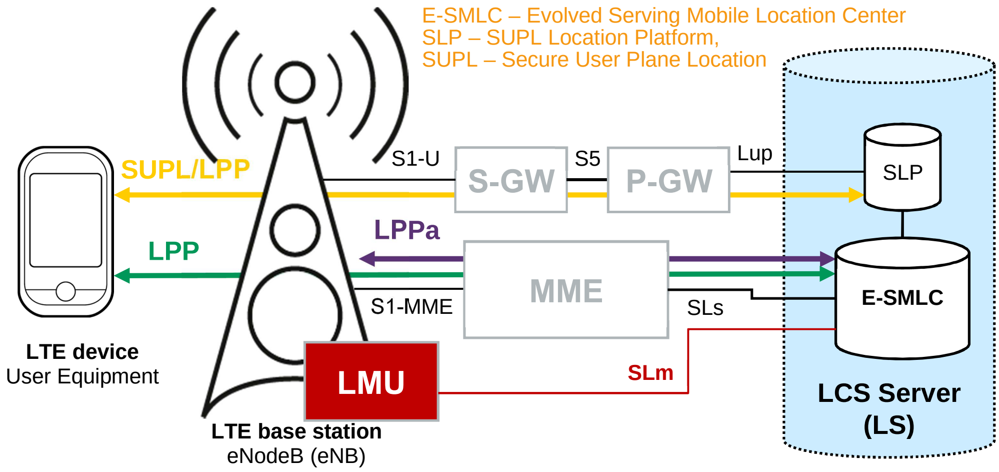

Fig. 2-16: E-UTRA supported positioning network architecture

In order to obtain uplink measurements, the LMUs need to know the characteristics of the SRS signal transmitted by the UE for the time period required to calculate uplink measurement. These characteristics need to be static over the periodic transmission of SRS during the uplink measurements. Furthermore the E-SMLC can indicate to the serving eNB the need to direct the UE to transmit SRS signals (up to the maximum SRS bandwidth applicable for the carrier frequency configured; as periodic SRS involving multiple SRS transmissions). However if the requested resources are not available, the eNB may assign other or even no resources. I.e. the final decision of SRS transmissions to be performed and whether to take into account this information is entirely up to the eNB implementation. Generally the E-SMLC requests multiple LMUs to perform uplink time measurements.

3GPP created the following new specifications to describe the new SLm interface:

- TS 36.456 SLm interface general aspects and principles
- TS 36.457 SLm interface: layer 1
- TS 36.458 SLm interface: signaling transport
- TS 36.459 SLm Interface: SLmAP Specification

The SLm transports SLm Application Protocol (SLmAP) messages over the E-SMLC-LMU interface. SLmAP is used to support the following functions:

- Delivery of target UE configuration data from the E-SMLC to the LMU
- Request positioning measurements from the LMU and delivery of positioning measurements to the E-SMLC

Furthermore the existing LTE Positioning Protocol Annex (LPPa) was enhanced to support uplink positioning. The LPPa supports the following positioning functions (new uplink positioning function highlighted in blue):

- E-CID cases where assistance data or measurements are transferred from the eNode B to the E-SMLC
- Data collection from eNodeBs for support of downlink OTDOA positioning

- **Retrieval of UE configuration data from the eNodeBs for support of uplink (e.g. UTDOA) positioning**

Finally the uplink timing measurement itself was defined in [8] as follows.

UL Relative Time of Arrival (TUL-RTOA)

The UL Relative Time of Arrival (TUL-RTOA) is the beginning of subframe i containing SRS received in LMU j, relative to the configurable reference time. The reference point for the UL relative time of arrival shall be the RX antenna connector of the LMU node when LMU has a separate RX antenna or shares RX antenna with eNB and the eNB antenna connector when LMU is integrated in eNB.

2.6 Service continuity improvements for MBMS

Although physical layer parameters were already specified in 3GPP Release 8, MBMS in LTE has been completed throughout all layers in 3GPP Release 9 (see [2] for details).

3GPP Release 10 makes provision for deployments involving more than one carrier by adding the carrier aggregation technology component (see [3]). The network can take into account a UE's capability to operate in a specific frequency band or multiple bands and also to operate on one or several carriers. Making the network aware of the services that the UE is receiving or is interested to receive via MBMS could facilitate proper action by the network e.g. handover to a target cell or reconfiguration of secondary cell(s), to facilitate service continuity of unicast services and desired MBMS services. The objective of this technology component in 3GPP Release 11 was essentially to provide continuity of the service(s) provided by MBSFN in deployment scenarios involving one or more frequencies. Note that the improvements were only specified for the same MBSFN area, i.e. there is no service continuity support between different MBSFN areas (see Fig. 2-17 for the basic MBMS architecture and interfaces).

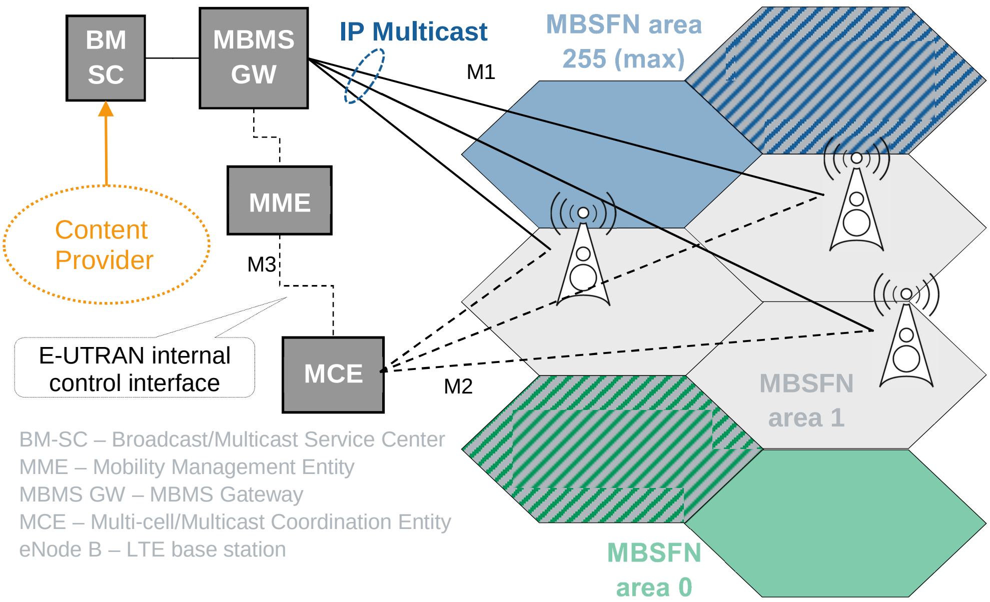

Fig. 2-17: MBMS architecture and interfaces

Thus within the same geographic area, MBMS services can be provided on more than one frequency and the frequencies used to provide MBMS services can change from one geographic area to another within the same PLMN.

For both situations, when the UE is in the RRC IDLE mode or when it is in the RRC CONNECTED mode, improvements for the service continuity were specified:

- For the idle mode, a reprioritization of the cell the UE is camped on was defined to be allowed for the duration of the service. Depending on the channel situation and received system information the UE selects the most pertinent cell to camp on when it is in the idle mode. Then it can only receive the desired MBMS service if it is transmitted on the cell the UE is camped on. The solution is that the UE may also camp on a suboptimal cell if this cell transmits the desired service. A new SIB15 guides the UE for this reselection. SIB15 contains
  - the list of MBMS Service Area Identities (SAIs) for the current frequency,
  - a list of neighboring frequencies that provide MBMS services and the corresponding MBMS SAIs
  - a list of MBMS SAIs for a specific frequency
- For the connected mode, signaling information was specified to improve the service continuity. In the current specification, service continuity when moving from one cell to another is only given, if both cells belong to the same MBSFN area. If the MBSFN area changes on a handover, the UE has to search again for the occurrence of the current service in all available frequencies and MCHs, which is time consuming. The user perceives this as a service interruption. The specified signaling allows the UE to immediately switch to the frequency and channel and can so avoid these long search times. Furthermore the UE provides a MBMSInterestIndication message, i.e.the frequencies which provide the service(s) that the UE is receiving or is interested to receive. The interest indication is provided at the frequency level rather than on an individual service. This message is sent whenever the UE interest changes with respect to the signalled information. The MBMSInterestIndication field also includes whether the UE prioritizes MBMS reception above unicast reception. Accordingly the LTE network reuses the SupportedBandCombination information element to derive the UEs MBMS related reception capabilities and hereby tries to ensure that the UE is able to receive MBMS and unicast bearers by providing them on the right frequencies.

Fig. 2-18 illustrates the communication between the UE and the LTE network.

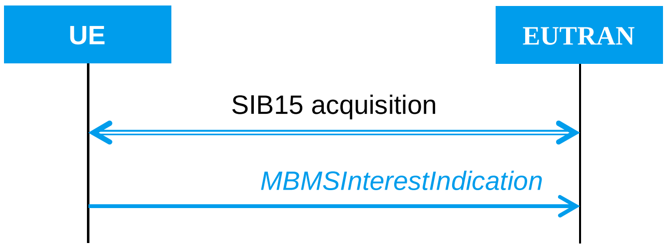

Fig. 2-18: MBMS interest indication [11]

2.7 Signaling / procedures for interference avoidance for In-Device Coexistence

Already today UEs contain several wireless technologies transmitting and/or receiving RF signals simultaneously. Besides cellular like GSM, WCDMA and/or LTE, there are also WLAN (used on industrial, scientific and medical (ISM) radio bands), Bluetooth and GNSS technologies in the device creating interferences caused by adjacent channel emissions, or receiving on the frequency of a technology which is on a harmonic or sub harmonic of the transmitting frequency. Due to extreme proximity of multiple radio transceivers within the same UE operating on adjacent frequencies or sub-harmonic frequencies, the interference power coming from a transmitter of the collocated radio may be much higher than the actual received power level of the desired signal for a receiver (see Fig. 2-19).

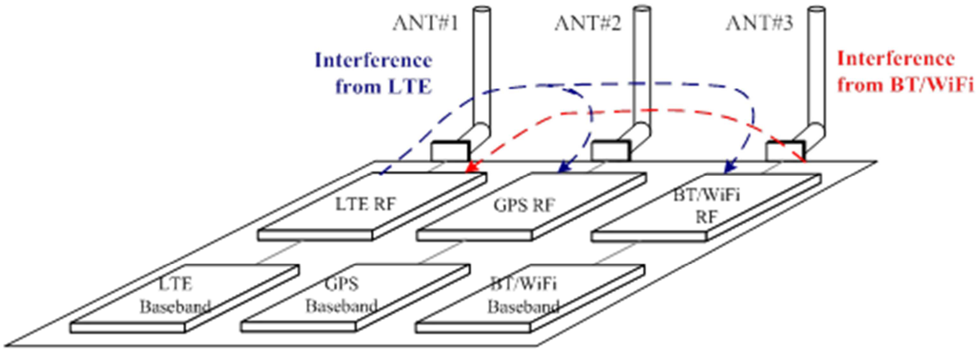

Fig. 2-19: Example implementation of LTE, GPS and WiFi in a single device

This situation causes In-Device Coexistence (IDC) interference. The goal of this interference avoidance technology component is to protect the different radios from the mentioned mutual interferences.

The solution specified in 3GPP Release 11 allows the UE to send an IDC indication via dedicated RRC signalling to the base station, if it cannot resolve the interference situation by itself. This should allow the base station to take appropriate measures. The details of the IDC indication trigger are left up to UE implementation.

The base station can resolve the IDC issue using the following methods:

- DRX based time domain solutions:
  An enhancement in the information element MAC-MainConfig was introduced. It mainly consists in the introduction of additional DRX values.
- Frequency domain solutions:
  The basic concept is to change the LTE carrier frequency by performing inter-frequency handover within E-UTRAN
- UE autonomous denials:
  There are two options, depending on the interference cause:
  - If LTE is interfered by an ISM transmission, the UE autonomously denies ISM transmissions to stay connected with the eNB in order to resolve IDC issues.
  - If an ISM transmission is interfered by LTE, the UE may autonomously deny LTE transmissions (UL grants) in order to protect rare ISM cases. This

method should only be used if there are no other IDC mechanisms available, because this way the LTE throughput is degraded. What exactly a *rare case* means is not specified. Instead, a long-term denial rate is signalled to the UE to limit the amount of autonomous denials. If this configuration is missing, the UE shall not perform any autonomous denials at all.

To assist the base station in selecting an appropriate solution, all necessary/available assistance information for both time and frequency domain solutions is sent together in the IDC indication. The IDC assistance information contains the list of carrier frequencies suffering from on-going interference and the direction of the interference. Additionally it may also contain time domain patterns or parameters to enable appropriate DRX configuration for time domain solutions on the serving LTE carrier frequency.

Note that the network is in the control of whether or not to activate this interference avoidance mechanism. The InDeviceCoexIndication message from the UE may only be sent if a measurement object for this frequency has been established. This is the case, when the RRCConnectionReconfiguration message from the eNB contains the information element idc-Config. The existence of this message declares that an InDeviceCoexIndication message may be sent. The IDC message indicates which frequencies of which technologies are interfered and gives assistance to possible time domain solutions. These comprise DRX assistance information and a list of IDC subframes, which indicate which HARQ processes E-UTRAN is requested to abstain from using. This information describes only proposals, it is completely up to the network to do the decisions.

Radio Resource Management (RRM) and radio link measurement requirements when a UE is provided with a IDC solution are specified in [14].

2.8 Enhancements for Diverse Data Applications (EDDA)

With the ever increasing use of applications used on smartphones, end users often complain about low battery life time. Beside the main power consumption drivers like e.g. the operation of the screen, different applications may cause small amount but frequent data traffic to be exchanged between user device and the network. Even terms like “signaling storm” have been used to describe the problem. In order to improve the power consumption impact, the technology component “EDDA” was introduced in 3GPP Release 11. The goal was to optimize user experience in the network by allowing the UE to ask for a more power efficient mode of operation. Note that the reaction from the network is not specified but is completely up to implementation, which means that it is pure UE assistance information and not a trigger to a specified reaction.

Two information elements to be sent from the UE to the eNB are foreseen:

- UE preference for power optimised configuration (PowerPreferenceIndicator (PPI))
  - If set to lowpowerconsumption, the UE indicates its preference for a configuration that is primarily optimised for power saving. This may comprise e.g. a long value for the DRX cycle and thus serves the background traffic

- If set to normal, the UE prefers the normal configuration, which corresponds to the situation that the PPI was never sent.

On the RRC level, the procedure of PPI transmission is defined according to Fig. 2-20. The UE may only send the assistance information to eNodeB if it is configured before. This is done via a powerPrefIndicationConfig information element contained in the RRCConnectionReconfiguration message. The configuration may be done either during any reconfiguration on the serving cell, or in the RRCConnectionReconfiguration message sent in the handover to E-UTRA.

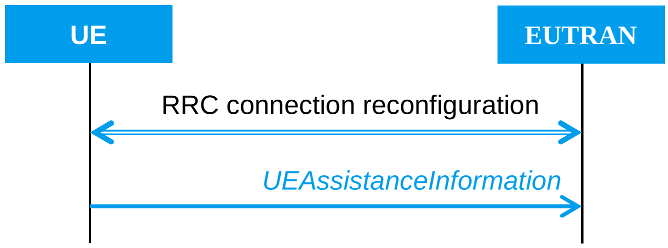

Fig. 2-20: UE Assistance Information [11]

2.9 RAN overload control for Machine Type Communication

A large number of Machine Type Communication (MTC) devices are expected to be deployed in a specific area, thus the network has to face increased load as well as possible surges of MTC traffic. Note that 3GPP uses the term MTC, whereas often also M2M is used in the industry for the same type of devices. Radio network congestion may happen due to the mass concurrent data and signaling transmission. One example of the overload situation may be, if after a power failure all MTC devices used in a skyscraper access the network at the same time. This may cause intolerable delays, packet loss or even service unavailability. The objective of this technology component was to specify Extended Access Barring (EAB) mechanisms for RAN overload control for both UMTS and LTE networks. The EAB mechanism is suitable for but not limited to Machine-Type Communications.

The solution applied for LTE is the introduction of a new System Information Block (SIB) Type14, which contains information about Extended Access Barring for access control. The content is essentially a bitmap (0…9). Additionally new SIB14 content is indicated via paging messages. This avoids unnecessary impact on non-EAB UEs. Access Class related cell access restrictions, if it is sent as a part of Extended Access Barring parameters, need to be checked by the UE before sending an RRC Connection Request message or Initial Direct Transfer. See Fig. 2-21 illustrating the procedure for access barring.

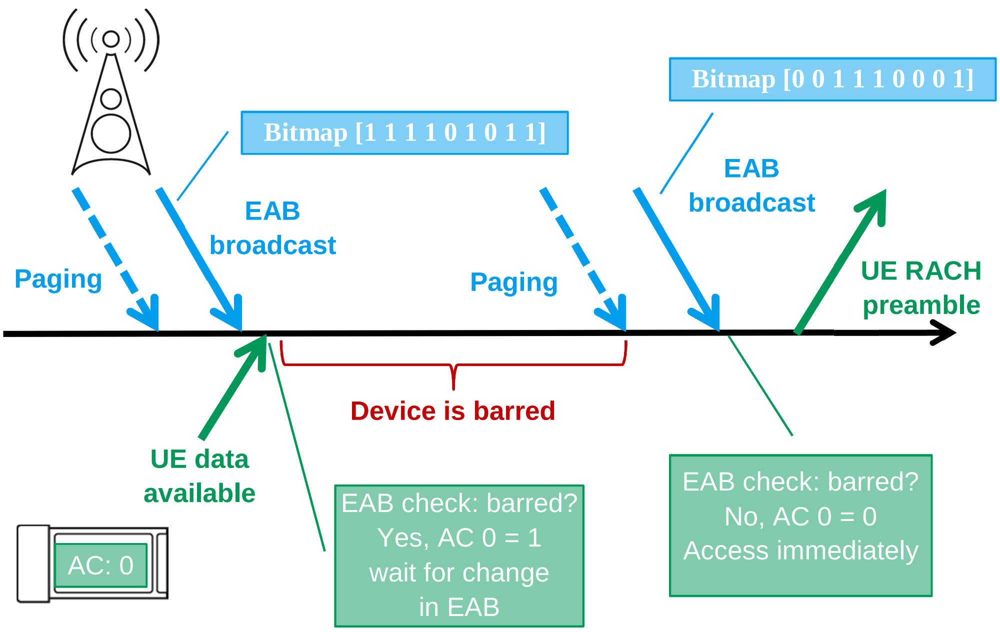

Fig. 2-21: EAB principle

2.10 Minimization of Drive Test (MDT)

The goal of MDT is to get information of the current network from measurements taken by the UE. Combining these measurements with information from the RAN, network optimization can be done in an efficient way. As a consequence, drive tests shall be decreased and only necessary for measurements which are not available for a UE. Examples are detailed monitoring of the channel impulse response to check inter-symbol interference in multi-path environments, the identification of external interferences or cases where the better measurement accuracy and speed of a high end network scanner is of great importance. This includes the possibility to benchmark different mobile networks or radio channel sounding, e.g. for checking the MIMO performance of radio channels. Also Speech quality and video quality measurements will continue to require dedicated drive tests. In this way, MDT does not replace drive tests but rather provides complimentary enhancements. Note that although MDT is strongly related to Self-Organizing Networks (SON), it is independent of it. Its output is a necessary ingredient for SON, but can also be used for a manual network optimization. MDT was discussed for the first time in a 3GPP Release 9 when several use cases were defined and analyzed. From those, the Coverage Optimization (CO) use case was specified in Release 10 together with a basic measurement framework. This framework was then enhanced in Release 11 and additional use cases mainly concerning Quality of Service (QoS) related issues were included.

Location Information is important for MDT. At least the longitude and latitude of the measurement sample is given. Typically GNSS based positioning methods like GPS is used, but also the observed time difference of arrival (OTDOA), assisted GPS or Secure User-Plane Location (SUPL) may be used. In 3GPP Release 10, location information was applied in a *best-effort* way, which means that it is included by UE if available. In 3GPP Release 11, location information may be requested by the network for measurements in the connected mode. Certainly this location information is still optional, because the user may have manually disabled the GPS hardware or there was no sufficient satellite coverage during the MDT measurement.

2.10.1 Architecture

The selected architecture for the MDT measurements is the so called *Control Plane* approach, where UE Measurements are controlled by the protocol stack of the air interface. This ensures an autonomic control of the measurements within the access network. There are two ways for an operator to control the measurements: In the *management-based MDT*, the measurements are intended for a special geographic area and the UEs are randomly selected by the RAN. In the *signaling-based MDT*, measurements are intended for specific subscribers (Fig. 2-22).

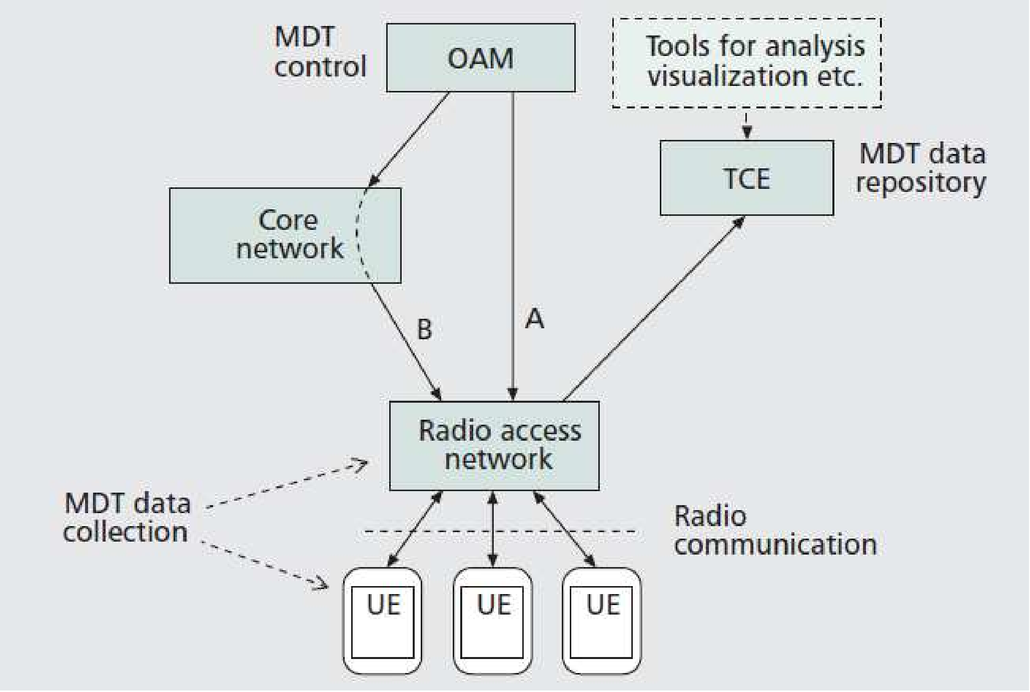

Fig. 2-22: Measurement control of MDT by the OAM. Path A denotes the management-based MDT, path B the signaling-based MDT (source [16]).

MDT is always triggered by the OAM. It provides the measurement configuration either directly to the eNB (management-based MDT) or to the MME (signaling-based MDT) which forwards it to the pertinent eNB. The reason for the latter path is that it is the MME which has the knowledge about the cells where the UE under consideration are located. The eNB then configures the UEs, for which an extra call setup may be initialized if necessary. After the measurements have been taken, the UE sends them to the eNBs where the measurement results are collected and forwarded to the Trace Collection Entity (TCE).

2.10.2 Use Cases

Up to 3GPP Release 11 there are two classes of use cases defined: Coverage use cases and QoS related use cases.

Coverage Use Cases

Coverage use cases are defined in order to identify regions of coverage problems which were not identified by planning tools. These comprise regions of weak coverage even up to coverage holes. Additionally also pilot pollution may cause problems, i.e. signals of different cells overlap in an unintentional way. They produce interferences leading to a degradation of the service quality. Even with network planning these situations may occur e.g. when larger buildings are constructed or pulled down.

These measurements are not restricted to regions with coverage issues. It is also beneficial to have a coverage mapping indicating the signal (and interference) levels in all regions of a cell in order to optimize further network extensions, e.g. the best location of a pico cell.

Another important aspect is the determination of the actual cell boundaries for both, intra and inter-RAT handovers during a connection. Handover problems may be related to changed cell boundaries and can be identified this way. This situation occurs frequently on the *Overshoot ranges*, which are regions where the coverage of a cell reaches far beyond the planned range. Call drops, ping-pong handovers and reduced data throughput may result.

There are also MDT measurements defined for the eNodeBs. One use case of them is to monitor the UL coverage, which is especially important for FDD scenarios with a large frequency gap between UL and DL.

QoS Verification Use Cases

These use cases are defined to assess QoS experience by a specific user and to monitor locations of large data transfers. The latter one helps network operators to identify where a small cell extension would be most beneficial in order to cope with increased capacity requirements.

2.10.3 Measurements

For realizing the MDT functionalities, existing measurements are reused as far as possible. Two modes exist:

- Logged MDT: This mode is used when the UE is in the RRC_IDLE state. Measurements are stored in the UE and reported to the eNB on a later occasion by means of the UE Information procedure.
- Immediate MDT: In this mode, the measurement results are reported immediately to the eNBs. Thus, it is applied when the UE is in the RRC_CONNECTED state.

Throughout the specification phase of 3GPP Release 11 it turned out that these two modes were not sufficient for all use cases of interest. Therefore Accessibility Measurements were introduced. These concern the RRC Connection Establishment failures, but also Radio Link Failures and HO failures are treated similarly. Their reporting has to be dealt with in a special way.

Logged MDTs are optional for user devices; its availability is indicated in the UE capabilities. Immediate MDTs are always supported by a UE, because they rely on conventional RRM measurements. However, it is optional whether the UE is able to support detailed location information therein. Finally, Accessibility MDTs are mandatory.

2.10.3.1 Logged Measurements

Logged measurements comply with the principles of idle mode measurements as specified in [14]. MDT logging is performed only in the camped normally state on cells which are not excluded by a possible configured areaConfiguration [11]. In other idle states, MDT measurements are suspended.

The procedure is initiated by the RRC of the network by sending a DL–DCCH message *(*LoggedMeasurementsConfiguration*)*. When the conditions for measurement logging are fulfilled, the measurements take place at the time stamps given by the Logging interval. Only while the UE is in the idle state there is a measurement logging. It is suspended when the UE transits to the connected state. Measurement results have to be kept in the UE for at least 48 hours. In addition, logging configuration and data collected are discarded when the UE is switched off or detaches from the network.

The presence of logged measurements is indicated to the eNB on an RRCConnectionSetupComlete, RRCConnectionReconfigurationComplete (for handover) or RRCConnectionReestablishmentComplete message.

This process maybe started from the eNB at any time and is not restricted to the time immediately after having received the indication of availability. The response from the UE contains a list of the following measurement results:

- Location information (optional): Position with uncertainty information.
- Time information of the measurements with an accuracy of 1 second
- Global cell ID of the cell the UE is camping on
- TraceReference and TraceRecordingSession
- RSRP, RSRQ of cell the UE is camped on
- Measurement results of neighboring cells (intra/inter RAT, optional)
- Carrier frequency for inter–frequency and inter–RAT neighbors

2.10.3.2 Immediate Measurements

For immediate MDT, the configuration is based on the existing RRC measurement procedures for configuration and reporting. In addition, there are extensions for location information defined, which are however optional for the UE to support. In contrast to the logged measurements, time stamps are provided by the eNB.

Up to 3GPP Release 11 there are two MDT measurements for the UE defined:

- M1: RSRP and RSRQ measurements according to [8]. Measurement report may be triggered either as periodic, event based with event A2, or event triggered periodic with the event A2. The last one may be used when measurements in problematic regions shall be collected.
- M2: Power Headroom measurements [7]. These are carried by MAC signaling, so the existing mechanism of PHR transmission applies [10].

MDT measurements are configured via the "RRC Connection Reconfiguration" process in the same way as conventional RRM measurements are set up. The main difference to those measurements is the inclusion of GNSS location information.

Reporting is done in the same way as conventional measurement reports. Each time the trigger condition is fulfilled, the UE sends a corresponding report. These reports are collected in the eNB and forwarded to the TCE. For immediate MDT, the time information of the GNSS positioning estimation is provided in order to estimate its validity.

2.10.3.3 Accessibility Measurements, Handover (HO) failure and Radio Link Failure (RLF)

Strictly speaking, the accessibility measurements concern only the connection establishment failure. However, handover failures and radio link failures are treated in a similar way. There is no need of a prior configuration from the network, the UE automatically stores the failure information and indicates its presence on a subsequent RRCConnectionSetupComplete, RRCConnectionReconfigurationComplete (for handover) or RRCConnectionReestablishmentComplete message, provided that the UE is attached to a network where it is supposed to report these failures. If the eNB gets an indication about such a failure and wants to retrieve this information, it uses the same information retrieval process as for the logged MDT measurements.

2.10.3.4 QoS Related Measurements

In addition to the measurements defined above, there are 3 additional ones carried out by the eNB in order to monitor the QoS related data and to monitor the UL quality:

- M3: Received Interference Power measurements
- M4: Data Volume measurements
- M5: Scheduled IP Throughput

Additionally there are IP throughput and data volume measurements. IP throughput is mainly intended for measuring the throughput when the radio interface is the bottleneck. The objective is to access over Uu the IP throughput independent of traffic patterns and packet size. The data volume measurement serves to determine the location and amount of traffic within a cell. This might be useful to determine the location of additional (small cells) needed for capacity requirements.

2.11 Network Energy Saving

The power efficiency in the infrastructure and terminal is an essential part of the cost-related requirements in LTE-Advanced. There was a strong need to investigate possible network energy saving mechanisms to reduce CO_2 emission and OPEX of mobile network operators. Up to and including 3GPP Release 10 both intra-eNodeB and inter-eNodeB energy saving mechanism was introduced. The basic method is to partly switch off eNodeBs, which cover the same area, when capacity is not needed, e.g. during night times. 3GPP conducted a study on possible solutions and concluded that OAM-based approach and signaling-based approach, as well as hybrid approaches, are feasible, applicable and backward compatible for improving energy efficiency.

In 3GPP Release 11 the method was enhanced to cover the inter RAT case. In a deployment where capacity booster cells can be distinguished from cells providing basic coverage, energy consumption can be optimized. LTE cells providing additional capacity can be switched off when its capacity is no longer needed and can be re-activated on a need basis. The basic coverage in that case may be provided by (other) LTE, UMTS or GSM cells. The eNodeB indicates the switch-off action to a GSM and/or UMTS node by means of the eNodeB Direct Information Transfer procedure over the S1 interface (see [4]).

3 Conclusion

This white paper describes the enhancements to LTE-Advanced provided within 3GPP Release 11. Beside enhancements to features introduced in 3GPP Release 10, such as carrier aggregation, new features like Coordinated Multi-Point for LTE (CoMP) in Downlink and Uplink are introduced. CoMP itself, as well as MIMO enhancements standardized with 3GPP Release 10 as well as the desire to further mitigate inter-cell interference for various deployment scenarios, require the definition of a new control channel, the Enhanced PDCCH. E-PDCCH adds new complexity to the physical layer. The carrier aggregation enhancements, especially multiple timing advances impact the physical layer even further. CoMP itself has a significant impact to the overall network complexity. The overall goal of 3GPP Release 11 is to complete features that where introduced with Release 10 (e.g. carrier aggregation) and further add functionality to mitigate inter-cell interference and optimize cell edge performance of devices. It is noted that many of the technology components result from the demand to more efficiently support heterogeneous network topologies.

4 LTE / LTE-Advanced frequency bands

Operating bands of LTE/LTE-A up to 3GPP Release 11 are shown in Table 4-1 using paired spectrum and in Table 4-2 using unpaired spectrum.

Table 4-1

Operating FDD bands for LTE / LTE-Advanced							
Operating Band	**Uplink (UL) operating band BS receive/UE transmit**			**Downlink (DL) operating band BS transmit /UE receive**			**Duplex Mode**
	F_{UL_low} [MHz]	-	F_{UL_high}	F_{DL_low}	-	F_{DL_high}	
1	1920	-	1980	2110	-	2170	FDD
2	1850	-	1910	1930	-	1990	
3	1710	-	1785	1805	-	1880	
4	1710	-	1755	2110	-	2155	
5	824	-	849	869	-	894	
6	830	-	840	865	-	875	
7	2500	-	2570	2620	-	2690	
8	880	-	915	925	-	960	
9	1749.9	-	1784.9	1844.9	-	1879.9	
10	1710	-	1770	2110	-	2170	
11	1427.9	-	1447.9	1475.9	-	1495.9	
12	699	-	716	729	-	746	
13	777	-	787	746	-	756	
14	788	-	798	758	-	768	
15	Reserved			Reserved			
16	Reserved			Reserved			
17	704	-	716	734	-	746	
18	815	-	830	860	-	875	
19	830	-	845	875	-	890	
20	832	-	862	791	-	821	
21	1447.9	-	1462.9	1495.9	-	1510.9	
22	3410	-	3500	3510	-	3600	
23	2000	-	2020	2180	-	2200	
24	1626.5	-	1660.5	1525	-	1559	
25	1850	-	1915	1930	-	1995	
26	814	-	849	859	-	894	
27	807	-	824	852	-	869	
28	703	-	748	758	-	803	
29				717	-	728	

Table 4-2

Operating TDD bands for LTE / LTE-Advanced							
Operating Band	**Uplink (UL) operating band BS receive/UE transmit**			**Downlink (DL) operating band BS transmit /UE receive**			**Duplex Mode**
	F_{UL_low} [MHz]	**-**	F_{UL_high}	F_{DL_low}	**-**	F_{DL_high}	
33	1900	-	1920	1900	-	1920	TDD
34	2010	-	2025	2010	-	2025	
35	1850	-	1910	1850	-	1910	
36	1930	-	1990	1930	-	1990	
37	1910	-	1930	1910	-	1930	
38	2570	-	2620	2570	-	2620	
39	1880	-	1920	1880	-	1920	
40	2300	-	2400	2300	-	2400	
41	2496	-	2690	2496	-	2690	
42	3400	-	3600	3400	-	3600	
43	3600	-	3800	3600	-	3800	
44	703	-	803	703	-	803	

5 Literature

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[16] J. Johansson, W. Hapsari, S.. Kelley, G. Bodog "Minimization of Drive Tests in 3GPP Release 11", IEEE Communications Magazine, Nov. 2012.

6 Additional Information

Please send your comments and suggestions regarding this application note to

TM-Applications@rohde-schwarz.com

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Regional contact

Europe, Africa, Middle East
+49 89 4129 12345
customersupport@rohde-schwarz.com

North America
1-888-TEST-RSA (1-888-837-8772)
customer.support@rsa.rohde-schwarz.com

Latin America
+1-410-910-7988
customersupport.la@rohde-schwarz.com

Asia/Pacific
+65 65 13 04 88
customersupport.asia@rohde-schwarz.com

China
+86-800-810-8228 /+86-400-650-5896
customersupport.china@rohde-schwarz.com

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