SAI Technology Inc.

LTE Advanced

White Paper

Reza Golshan

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This paper addresses the performance targets and the technology components being studied by 3GPP for LTE-Advanced. The high level targets of LTE-Advanced are to meet or exceed the IMT-Advanced requirements set by ITU-R. A short history of the LTE standard is offered, along with a discussion of its standards and performance. The technology components considered for LTE-Advanced include extended spectrum flexibility to support up to 100MHz bandwidth, enhanced multi-antenna solutions with up to eight layer transmission in the downlink and up to four layer transmission in the uplink, coordinated multi-point transmission/reception, the use of advanced relaying and heterogeneous network deployments.

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1. Introduction

Motivated by the increasing demand for mobile broadband services with higher data rates and Quality of Service (QoS), 3GPP started working on two parallel projects, Long Term Evolution (LTE) and System Architecture Evolution (SAE), which are intended to define both the radio access network (RAN) and the network core of the system, and are included in 3GPP Rel-8. LTE/SAE, also known as the Evolved Packet System (EPS), represents a radical step forward for the wireless industry that aims to provide a highly efficient, low-latency, packet-optimized, and more secure service. The main radio access design parameters of this new system include OFDM waveforms in order to avoid the inter symbol interference that typically limits the performance of high-speed systems, and MIMO (Multiple-Input Multiple-Output) techniques to boost the data rates. At the network layer, an all-IP flat architecture supporting QoS has been defined.

LTE mobile communication systems have been deployed as a natural evolution of GSM (Global system for mobile communications) and UMTS (Universal Mobile Telecom System). The ITU identified IMT-Advanced to identify mobile systems whose capabilities go beyond those of IMT 2000 (International Mobile Telecommunications). The formal definition of the fourth generation wireless, known as the International Mobile Telecommunications Advanced (IMT Advanced) project, was finally published by ITU-R in July 2008. Before 3GPP started working in the real 4G wireless technology, minor changes were introduced in LTE through Release 9. In particular, femtocells and dual-layer beamforming, predecessors of future LTE-Advanced technologies, have been added to the standard.

In September 2009 the 3GPP Partners made a formal submission to the ITU proposing that LTE Release 10 & beyond (LTE Advanced) should be evaluated as a candidate for IMT-Advanced. Beyond achieving technical requirements, a major reason for aligning LTE with the call for IMT-Advanced is that IMT conformant systems will be candidates for future new spectrum bands that are still to be identified. This ensures that today's deployed LTE mobile networks provide an evolutionary path towards many years of commercial operation. LTE-Advanced, is backward-compatible enhancement of LTE Release 8 that will be fully specified in 3GPP Release 10.

This white paper summarizes LTE-Advanced features and is organized as follows. In Section 2, we provide an overview of the LTE system architecture that will support the LTE and LTE-Advanced air interfaces. In Section 3, LTE-Advances requirements are introduced and in Section 4 the key components technology of LTE-Advanced that aims at increasing the system performance is explained in detail. Finally, we conclude the paper in Section 5.

2. LTE System Architecture Overview

In the context of 4G systems, both the air interface and the radio access network are being enhanced or redefined, but so far the core network architecture, i.e. the EPC, is not undergoing major changes from the already standardized SAE architecture. Therefore, in this section we give an overview of the E-UTRAN architecture and functionalities defined for the LTE-Advanced systems and the main EPC node functionalities, shared by Releases 8, 9, and 10.

2.1 EPC and E-UTRAN

EPS provides the user with IP connectivity to a PDN for accessing the Internet, as well as for running services such as Voice over IP (VoIP). An EPS bearer is typically associated with a QoS. Multiple bearers can be established for a user in order to provide different QoS streams or connectivity to different PDNs. For example, a user might be engaged in a voice (VoIP) call while at the same time performing web browsing or FTP download. A VoIP bearer would provide the necessary QoS for the voice call, while a best-effort bearer would be suitable for the web browsing or FTP session. The network must also provide sufficient security and privacy for the user and protection for the network against fraudulent use.

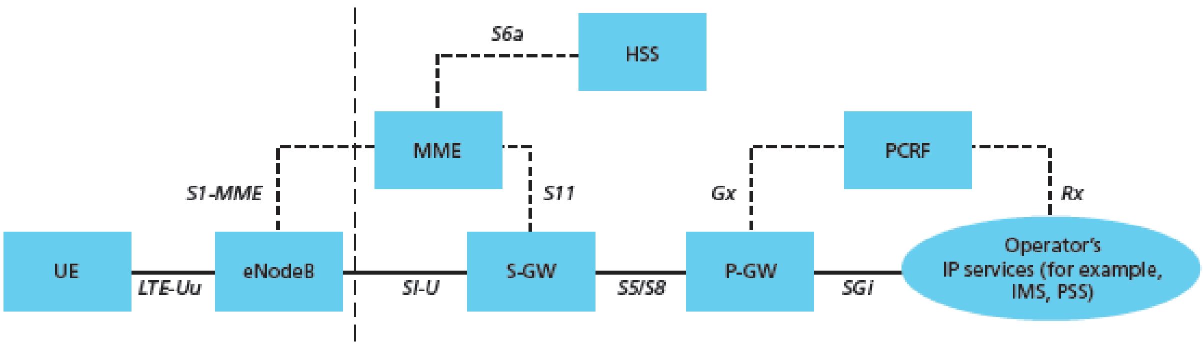

Figure 1: EPS Network Elements

This is achieved by means of several EPS network elements that have different roles. **Figure 8** shows the overall network architecture, including the network elements and the standardized interfaces. At a high level, the network is comprised of the CN (EPC) and the access network E-UTRAN. While the CN consists of many logical nodes, the access network is made up of essentially just one node, the evolved NodeB (eNodeB), which connects to the UEs. Each of these network elements is interconnected by means of interfaces that are standardized in order to allow multi-vendor interoperability. This gives network operators the possibility to source different network elements from different vendors. In fact, network operators may choose in their physical implementations to split or merge these logical network elements depending on commercial considerations. The functional split between the EPC and E-UTRAN is shown in **Figure 2**. The EPC and E-UTRAN network elements are described in more detail below.

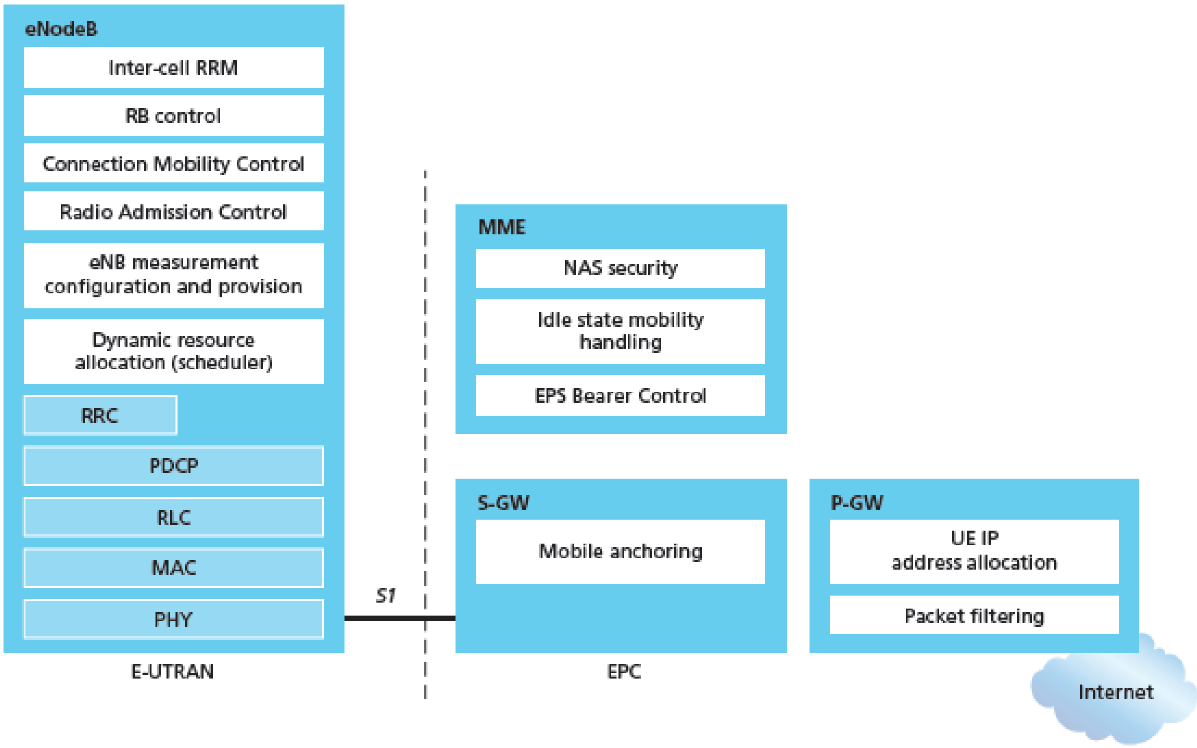

Figure 2: Functional split between E-UTRAN and EPC

2.1.1 *The Core Network*

The core network (called EPC in SAE) is responsible for the overall control of the UE and establishment of the bearers. The main logical nodes of the EPC are:

- PDN Gateway (P-GW)
- Serving Gateway (S-GW)
- Mobility Management Entity (MME)

2.1.2 *The Access Network*

The access network of LTE, E-UTRAN, simply consists of a network of eNodeBs, as illustrated in **Figure 3**. For normal user traffic (as opposed to broadcast), there is no centralized controller in E-UTRAN; hence the E-UTRAN architecture is said to be flat. The eNodeBs are normally interconnected with each other by means of an interface known as "X2" and to the EPC by means of the S1 interface — more specifically, to the MME by means of the S1-MME interface and to the S-GW by means of the S1-U interface. The protocols that run between the eNodeBs and the UE are known as the "AS protocols."

The E-UTRAN is responsible for all radio-related functions, which can be summarized briefly as:

- *Radio resource management (RRM)* – This covers all functions related to the radio bearers, such as radio bearer control, radio admission control, radio mobility control, scheduling and dynamic allocation of resources to UEs in both uplink and downlink.
- *Header Compression* – This helps to ensure efficient use of the radio interface by compressing the IP packet headers that could otherwise represent a significant overhead, especially for small packets such as VoIP.
- *Security* – All data sent over the radio interface is encrypted.
- *Connectivity to the EPC* – This consists of the signaling toward MME and the bearer path toward the S-GW.

On the network side, all of these functions reside in the eNodeB, each of which can be responsible for managing multiple cells. Unlike some of the previous second- and third-generation technologies, LTE integrates the radio controller function into the eNodeB. This allows tight interaction between the different protocol layers of the radio access network (RAN), thus reducing latency and improving efficiency. Such distributed control eliminates the need for a high-availability, processing-intensive controller, which in turn has the potential to reduce costs and avoid "single points of failure." Furthermore, as LTE does not support soft handover there is no need for a centralized data combining function in the network

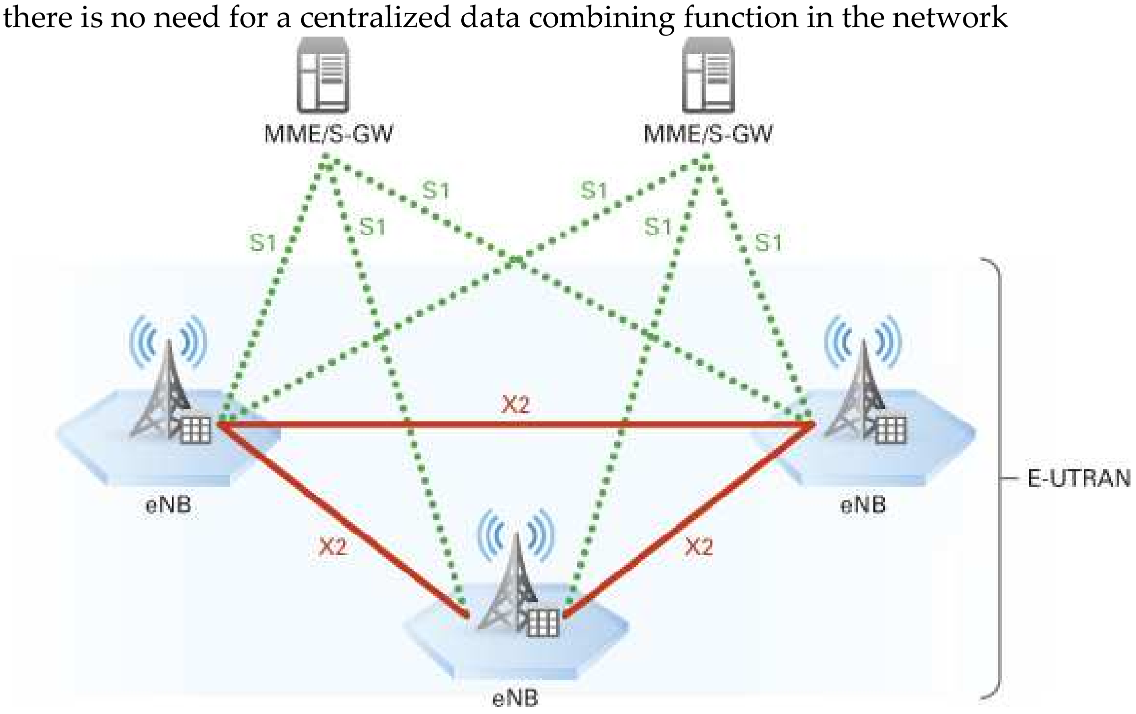

Figure 3: Overall E-UTRAN architecture

2.1.3 *The Roaming Architecture*

A network run by one operator in one country is known as a "public land mobile network (PLMN)." Roaming, where users are allowed to connect to PLMNs other than those to which they are directly subscribed, is a powerful feature for mobile networks, and LTE/SAE is no exception. A roaming user is connected to the E-UTRAN, MME and S-GW of the visited LTE network. However, LTE/SAE allows the P-GW of either the visited or the home network to be used, as shown in **Figure 4**. Using the home network's P-GW allows the user to access the home operator's services even while in a visited network. A P-GW in the visited network allows a "local breakout" to the Internet in the visited network.

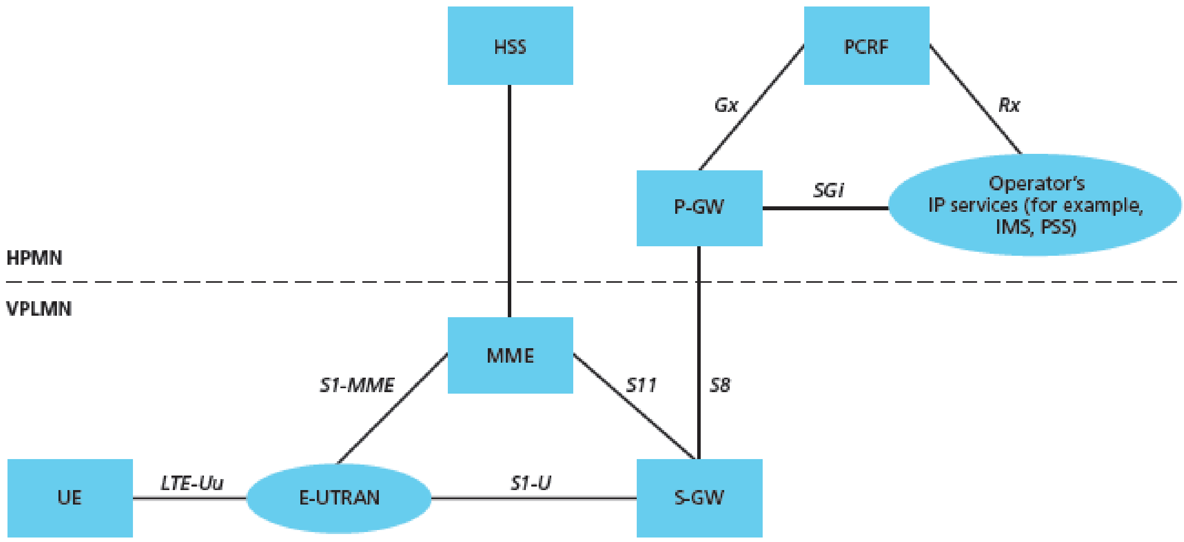

Figure 4: Roaming architecture for 3GPP accesses with P-GW in home network

2.1.4 *Internetworking with other Networks*

EPS also supports interworking and mobility (handover) with networks using other Radio Access Technologies (RATs), notably Global System for Mobile Communications (GSM), UMTS, CDMA2000 and WiMAX. The architecture for interworking with 2G and 3G GPRS/UMTS networks is shown in **Figure 5**. The S-GW acts as the mobility anchor for interworking with other 3GPP technologies such as GSM and UMTS, while the P-GW serves as an anchor allowing seamless mobility to non-3GPP networks such as CDMA2000 or WiMAX.

The P-GW may also support a Proxy Mobile Internet Protocol (PMIP)-based interface.

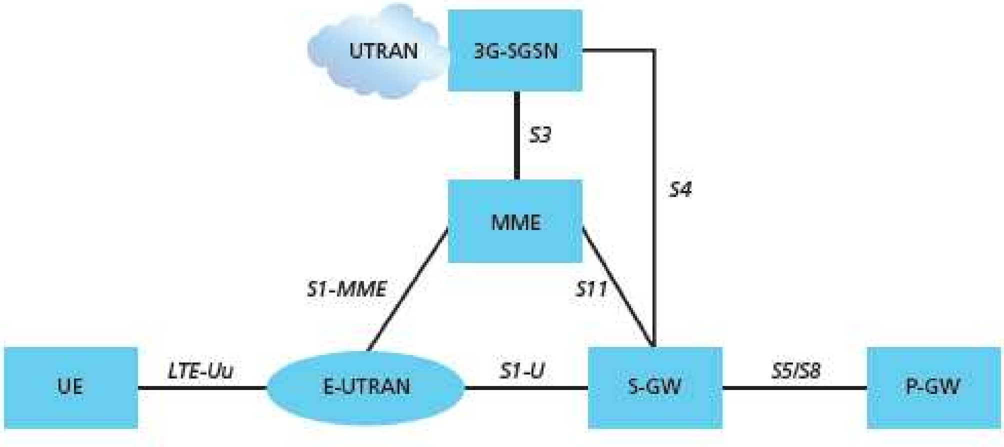

Figure 5: Architecture for 3G UMTS interworking

2.2 Protocol Architecture

2.2.1 *User Plane*

An IP packet for a UE is encapsulated in an EPC-specific protocol and tunneled between the P-GW and the eNodeB for transmission to the UE. Different tunneling protocols are used across different interfaces. A 3GPP-specific tunneling protocol called the GPRS Tunneling Protocol (GTP) is used over the CN interfaces, S1 and S5/S8. The E-UTRAN user plane protocol stack is shown in blue in **Figure 6**, consisting of the Packet Data Convergence Protocol (PDCP), Radio Link Control (RLC) and Medium Access Control (MAC) sublayers that are terminated in the eNodeB on the network side.

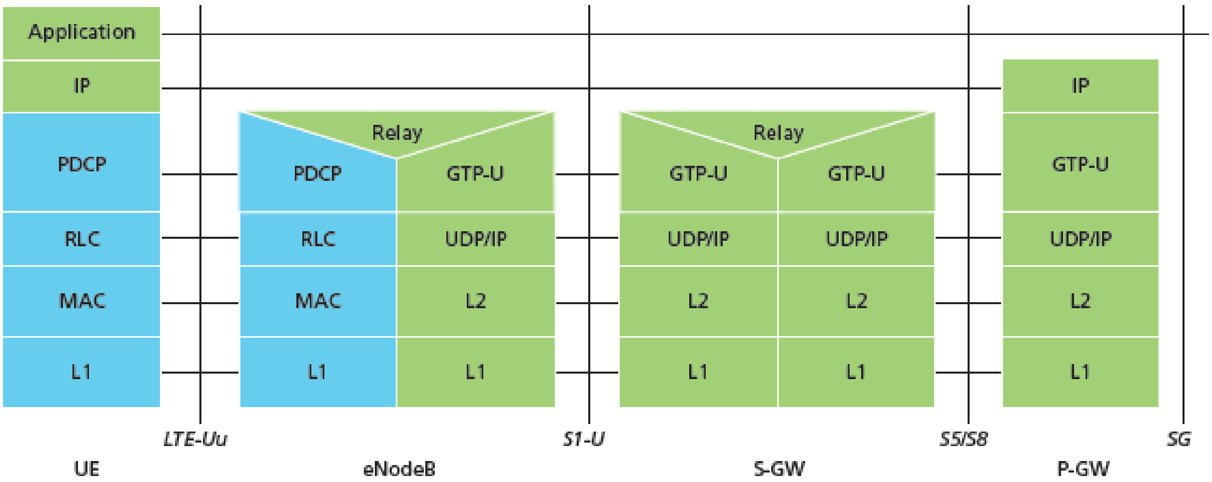

Figure 6: The E-UTRAN user plane protocol stack

2.2.2 Control Plane

The protocol stack for the control plane between the UE and MME is shown in **Figure 7**. The blue region of the stack indicates the AS protocols. The lower layers perform the same functions as for the user plane with the exception that there is no header compression function for the control plane.

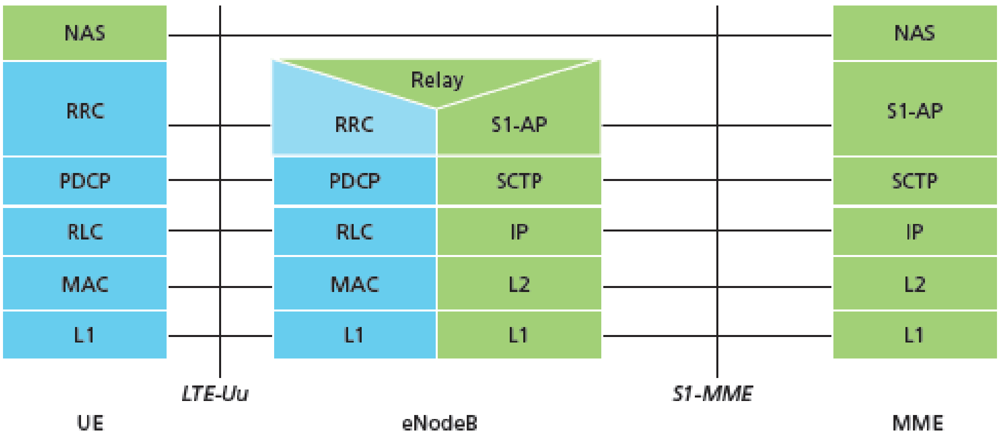

Figure 7: Control plane protocol stack

The Radio Resource Control (RRC) protocol is known as "layer 3" in the AS protocol stack. It is the main controlling function in the AS, being responsible for establishing the radio bearers and configuring all the lower layers using RRC signaling between the eNodeB and the UE.

2.3 Quality of service and EPS bearers

In a typical case, multiple applications may be running in a UE at any time, each one having different quality of service requirements. For example, a UE can be engaged in a VoIP call while at the same time browsing a web page or downloading an FTP file. VoIP has more stringent requirements for QoS in terms of delay and delay jitter than web browsing and FTP, while the latter requires a much lower packet loss rate. In order to support multiple QoS requirements, different bearers are set up within the Evolved Packet System, each being associated with a QoS. Broadly, bearers can be classified into two categories based on the nature of the QoS they provide:

- Minimum guaranteed bit rate (GBR) bearers that can be used for applications such as VoIP. These have an associated GBR value for which dedicated transmission resources are permanently allocated (for example, by an admission control function in the eNodeB) at bearer establishment or modification. Bit rates higher than the GBR may be allowed for a GBR bearer if resources are available. In such cases, a maximum bit rate (MBR) parameter, which can also be associated with a GBR bearer, sets an upper limit on the bit rate that can be expected from a GBR bearer.

- Non-GBR bearers that do not guarantee any particular bit rate. These can be used for applications such as web browsing or FTP transfer. For these bearers, no bandwidth resources are allocated permanently to the bearer.

In the access network, it is the responsibility of the eNodeB to ensure the necessary QoS for a bearer over the radio interface. Each bearer has an associated QCI, and an Allocation and Retention Priority (ARP). Each QCI is characterized by priority, packet delay budget and acceptable packet loss rate. The QCI label for a bearer determines how it is handled in the eNodeB. Only a dozen such QCIs have been standardized so that vendors can all have the same understanding of the underlying service characteristics and thus provide corresponding treatment, including queue management, conditioning and policing strategy. This ensures that an LTE operator can expect uniform traffic-handling behavior throughout the network regardless of the manufacturers of the eNodeB equipment. The set of standardized QCIs and their characteristics (from which the PCRF in an EPS can select) is provided in **Table 1**. The QCI table specifies values for the priority handling, acceptable delay budget and packet loss rate for each QCI label.

QCI	RESOURCE TYPE	PRIORITY	PACKET DELAY BUDGET (MS)	PACKET ERROR LOSS RATE	EXAMPLE SERVICES
1	GBR	2	100	10^{-2}	Conversational voice
2	GBR	4	150	10^{-3}	Conversational video (live streaming)
3	GBR	5	300	10^{-6}	Non-conversational video (buffered streaming)
4	GBR	3	50	10^{-3}	Real-time gaming
5	Non-GBR	1	100	10^{-6}	IMS signaling
6	Non-GBR	7	100	10^{-3}	Voice, video (live streaming), interactive gaming
7	Non-GBR	6	300	10^{-6}	Video (buffered streaming)
8	Non-GBR	8	300	10^{-6}	TCP-based (for example, WWW, e-mail), chat, FTP, p2p file sharing, progressive video and others
9	Non-GBR	9	300	10^{-6}	

Table 1: Standardized QCIs for LTE

3. LTE-Advanced Requirements Overview

LTE-Advanced was initiated by 3GPP with the purpose of finding the requirements and technology components so that the evolution of LTE would meet IMT-Advanced requirements. The first step is backwards compatibility with the existent version of LTE; this implies that an LTE node would see the LTE-Advanced network as an LTE network. Spectrum compatibility was required for a straightforward, low-cost progression to LTE-Advanced networks, similar to the evolution of WCDMA to HSPA. A set of IMT-Advanced high-level requirements established by the ITU-R are:

- A high degree of commonality of functionality worldwide while retaining the flexibility to support a wide range of services and applications in a cost-efficient manner.
- Compatibility of services within IMT and with fixed networks.
- Compatibility of internetworking with other radio access systems.
- High-quality mobile devices.
- User equipment suitable for worldwide use.
- User-friendly applications, services, and equipment.
- Worldwide roaming capability.
- Enhanced peak rates to support advanced services and applications up to 1 Gbit/s.

In addition, LTE-Advanced is intended to match or exceed the standards set by the ITU for IMT-Advanced with regards to capacity, data rates and low-cost deployment. A technical report summarizing LTE-Advanced requirements was generated by 3GPP which in general meet or exceed IMT-Advanced requirements. Additionally all existing LTE requirements are equally applicable to LTE Advanced. The LTE-Advanced requirements are detailed as follows:

Peak data rate

The system should target a downlink peak data rate of 1 Gbps and an uplink peak data rate of 500 Mbps.

Latency

C-Plane: The target for transition time from idle mode (with IP address allocated) to connected mode should be less than 50 ms including the establishment of the user plane (excluding the S1 interface transfer delay). The target for the transition from a "dormant state" to connected mode (i.e. discontinuous reception (DRX) substate in connected mode) should be less than 10 ms (excluding the DRX delay).

U-Plane: LTE-Advanced should allow for reduced U-plane latency compared to LTE Rel 8.

Spectrum efficiency

LTE-Advanced aims to support downlink (8x8 antenna configuration) peak spectrum efficiency of 30 bps/Hz and uplink (4x4 antenna configuration) peak spectrum efficiency of 15 bps/Hz. Additionally average spectrum efficiency targets have been set according to **Table 2**. Average spectrum efficiency is defined as the aggregate throughput of all users (the number of correctly received bits over a certain period of time) normalized by the overall cell bandwidth divided by the number of cells.

	Antenna Configuration	Target [bps/Hz/cell]
Uplink	1x2 / 2x4 / 4x4	1.2 / 2.0 / ???
Downlink	2x2 / 4x2 / 4x4 / 8x8	2.4 / 2.6 / 3.7 / ???

Table 2: Targets for average spectrum efficiency

Cell edge user throughput

LTE-Advanced should allow cell edge user throughput to be as high as possible. The cell edge user throughput is defined as the 5% point of the cumulative density function (CDF) of the user throughput normalized with the overall cell bandwidth. Requirements for cell edge performance are given in **Table 3** below.

	Antenna Configuration	Target [bps/Hz/cell/user]
Uplink	1x2 / 2x4 / 4x4	0.04 / 0.07 / ???
Downlink	2x2 / 4x2 / 4x4 / 8x8	0.07 / 0.09 / 0.12 / ??? /

Table 3: Targets for cell edge user throughput

Mobility

Mobility requirements have been formulated in comparison to LTE Release 8. The system shall support mobility across the cellular network for various mobile speeds up to 350km/h (or even up to 500km/h depending on the frequency band). In comparison to LTE Release 8, the system performance shall be enhanced for 0 up to 10 km/h.

Spectrum flexibility

LTE-Advanced shall operate in spectrum allocations of different sizes including wider spectrum allocations than those of LTE Release 8. Frequency division duplex (FDD) and time division duplex (TDD) should be supported for existing paired and unpaired frequency bands, respectively.

The initial identified frequency bands in addition to the already allocated bands in LTE Release 8 are as follows:

- 450-470 MHz band,
- 698-862 MHz band,
- 790-862 MHz band,
- 2.3-2.4 GHz band,
- 3.4-4.2 GHz band,
- 4.4-4.99 GHz band.

The relationship among the requirements of LTE-Advanced, and IMT Advanced are shown in **Table 4**. According to this table, it can be concluded that 3GPP LTE-Advanced requirements are a ***superset*** of the IMT-Advanced requirements i.e. LTE-Advanced is being designed to be a strong candidate for next 4G, since it fulfills or even exceeds all IMT-Advanced requirements. Other important requirements are the already mentioned backward compatibility of LTE-Advanced with LTE and the spectrum flexibility, i.e., the capacity of LTE Advanced to be deployed in different allocated spectra since each region or country has different regulations.

Item	IMT-Advanced	LTE-Advanced
Peak Data Rate (DL)	1 Gbps	1 Gbps
Peak Data Rate (UL)		500 Mbps
Spectrum Allocation	>40 MHz	Up to 100MHz
Latency (User Plane)	10 msec	10 msec
Latency (Control Plane)	100 msec	50 msec
Peak Spectral Efficiency (DL)	15 bps/Hz (4x4)	30 bps/Hz (8x8)
Peak Spectral Efficiency (UL)	6.75 bps/Hz (2x4)	15 bps/Hz (4x4)
Average Spectral Efficiency (DL)	2.2 bps/Hz (4x2)	2.6 bps/Hz (4x2)
Average Spectral Efficiency (UL)	1.4 bps/Hz (2x4)	2.0 bps/Hz (2x4)
Cell-Edge Spectral Efficiency (DL)	0.06 bps/Hz (4x2)	0.09 bps/Hz (4x2)
Cell-Edge Spectral Efficiency (UL)	0.03 bps/Hz (2x4)	0.07 bps/Hz (2x4)
Mobility	Up to 350 Km/h	Up to 350 Km/h

Table 4: IMT-ADVANCED REQUIREMENTS RELATED TO LTE-ADVANCED

4. LTE-Advanced Technological Components

In order to fulfill the rather challenging targets for LTE-Advanced, several key technology components are being investigated currently in 3GPP. The technology components considered for LTE-Advanced (Release 10 and beyond) are:

- Bandwidth extension (Carrier Aggregation)
- MIMO extension (Uplink & Downlink)
- Uplink multiple access extension
- Coordinated multiple point transmission and reception (CoMP)
- Advanced Relaying
- Heterogeneous network deployment
- Self-Optimizing Networks (SON) enhancements
- HNB and HeNB mobility enhancements

The new technology components of LTE-A spell a host of benefits for the CSP community: enabling performance improvements in peak data rates, average spectrum efficiency, cell edge performance, coverage, new ways of cost reduction in the process of deploying and operating networks with small base stations, and with cells without fixed transport connections.

Performance enhancements are summarized in **Table 5**.

	Peak Rate	Average Rate (Capacity)	Cell Edge Rate	Coverage
Carrier Aggregation	H	M	H	M
Uplink Multiple Access	H	H	N/A	N/A
MIMO Extension	H	H	H	N/A
CoMP	N/A	M	H	H
Relaying	N/A	N/A	M	H
Heterogeneous network	N/A	H	H	M

Table 5: Performance Enhancements of LTE-Advanced based on technology components

Following sections will provide details of each enhancement for LTE-Advanced.

4.1 Bandwidth Extension (Carrier Aggregation)

In order for LTE-Advanced to fully utilize the wider bandwidths of up to 100 MHz, while keeping backward compatibility with LTE, a carrier aggregation scheme has been proposed. Carrier aggregation consists of grouping several LTE ''component carriers'' (CCs) (e.g. of up to 20 MHz), so that the LTE-Advanced devices are able to use a greater amount of bandwidth (e.g. up to 100 MHz), while at the same time allowing LTE devices to continue viewing the spectrum as separate component carriers. In **Figure** 8 we illustrate the concept of Carrier aggregation in contiguous bandwidth.

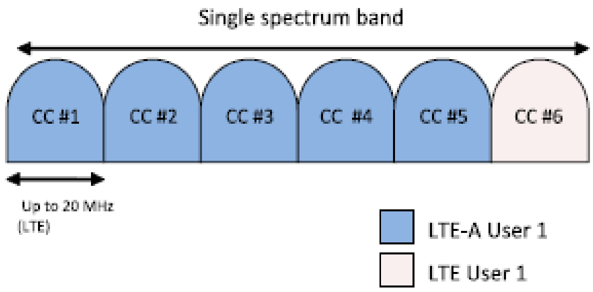

Figure 8: Carrier aggregation in contiguous bandwidth

It may not be always possible for an operator to obtain 100 MHz of contiguous spectrum. For this reason, the use of noncontiguous carrier aggregation is also proposed. In this case, the component carriers that are going to be aggregated can be noncontiguous in the same spectrum band or noncontiguous in different spectrum bands.

Figure 9 illustrates the case of noncontiguous carrier aggregation in the same band. The figure shows two LTE devices using bandwidths of up to 20 MHz, coexisting with an LTE-Advanced device that is using noncontiguous aggregated bandwidth of up to 100 MHz.

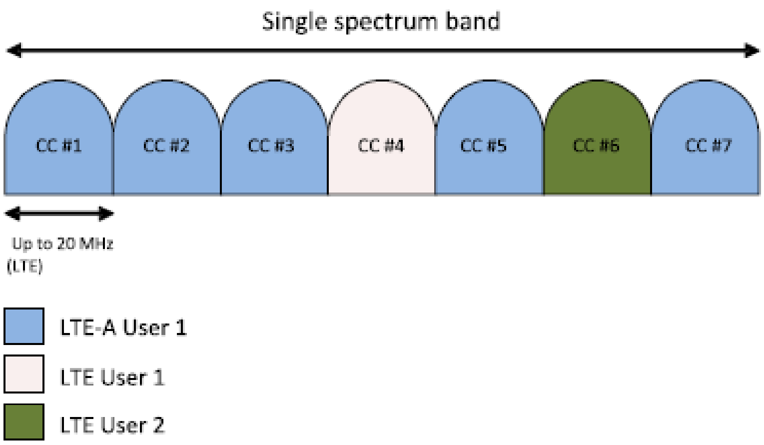

Figure 9: Carrier aggregation in in non-contiguous bandwidth, single band

Figure 10 illustrates the case of noncontiguous carrier aggregation in different bands, which could result from the simultaneous use of the spectrum bands. Two devices shown using bandwidths of up to 20 MHz, each one in a different spectrum band, coexisting with an LTE-Advanced device that is using noncontiguous aggregated bandwidth from different spectrum bands. The used bands can be dedicated or shared. In all the cases, the number of UL and DL CCs, as well as their bandwidths, might be different. Even within a single eNB, different UEs will be configured with different numbers of CCs, according to their capabilities, channel conditions, data rate requirements, and QoS requirements.

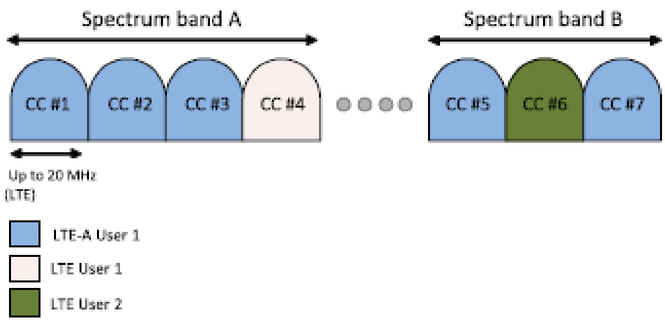

Figure 10: Carrier aggregation in in non-contiguous bandwidth, multiple bands

Carrier aggregation not only helps to achieve higher peak data rates, but could also help to achieve better coverage for medium data rates. It allows the use of lower orders of modulation and lower code rates, which would reduce the required link budget, transmission power, and interference. LTE-Advanced initial approach for carrier aggregation specifies four deployment scenarios as shown in **Table 6**. These scenarios cover both contiguous and non-contiguous carrier aggregation for single and multiple spectrum bands using TDD and FDD schemes.

Scenario	Mode	Spec	BW	No. of CCs	Band
A	FDD	Single-band contiguous	UL: 40 MHz DL: 80 MHz	UL: Contiguous 2 x 20 MHz DL: Contiguous 4x 20 MHz	Band 40 (3.5 GHz)
B	TDD	Single-band contiguous	UL/DL: 100 MHz	Contiguous 5 x 20 MHz	Band 40 (3.5 GHz)
C	FDD	Multi-band non-contiguous	UL: 40 MHz DL: 40 MHz	UL/DL: Non-contiguous 10 MHz Band 1 + 10 MHz Band 3 + 20 MHz Band 7	Band 1 (2.1 GHZ) Band 3 (1.8 GHz) Band 7 (2.6 GHz)
D	TDD	Multi-band non-contiguous	UL/DL: 90 MHz	Non-contiguous: 2 x 20 MHz Band 39 + 10 MHz Band 34 + 2 x 20 MHz Band 40	Band 39 (1.8 GHz) Band 34 (2.1 GHz) Band 40 (2.3 GHz)

Table 6: Primary LTE- Advanced deployment scenarios

4.1.1 *User plane*

Figure 11 illustrates the downlink and uplink layer 2 structure in case of carrier aggregation. It becomes obvious that the packet data control protocol (PDCP) and radio link control (RLC) layer are reused from LTE Release 8 operation. In contrast to LTE Release 8 one UE may be multiplexed to several component carriers, whereas there is one transport block and one independent hybrid acknowledge request (HARQ) entity per scheduled component carrier.

For the downlink, the scheme chosen for multiple access is to perform parallel transmission of transport blocks (TBs) at each CC, based on OFDMA, as in LTE. In each CC, a single TB (or two TBs in case of spatial multiplexing) is transmitted; also, each CC manages its own HARQ process. Furthermore, most of the upper-layer protocols of LTE are reused, since the multi-carrier nature of the physical layer is exposed as parallel paths up to the MAC layer. In this way, most of the development and investment done for LTE devices can be extended to LTE-Advanced.

In the uplink, LTE uses DFT pre-coded OFDM. For LTE-Advanced there is one DFT per component carrier, supporting contiguous and frequency-non-contiguous resource allocation on each CC. As for the downlink, the objective is to reuse and extend most of what has already been developed for LTE.

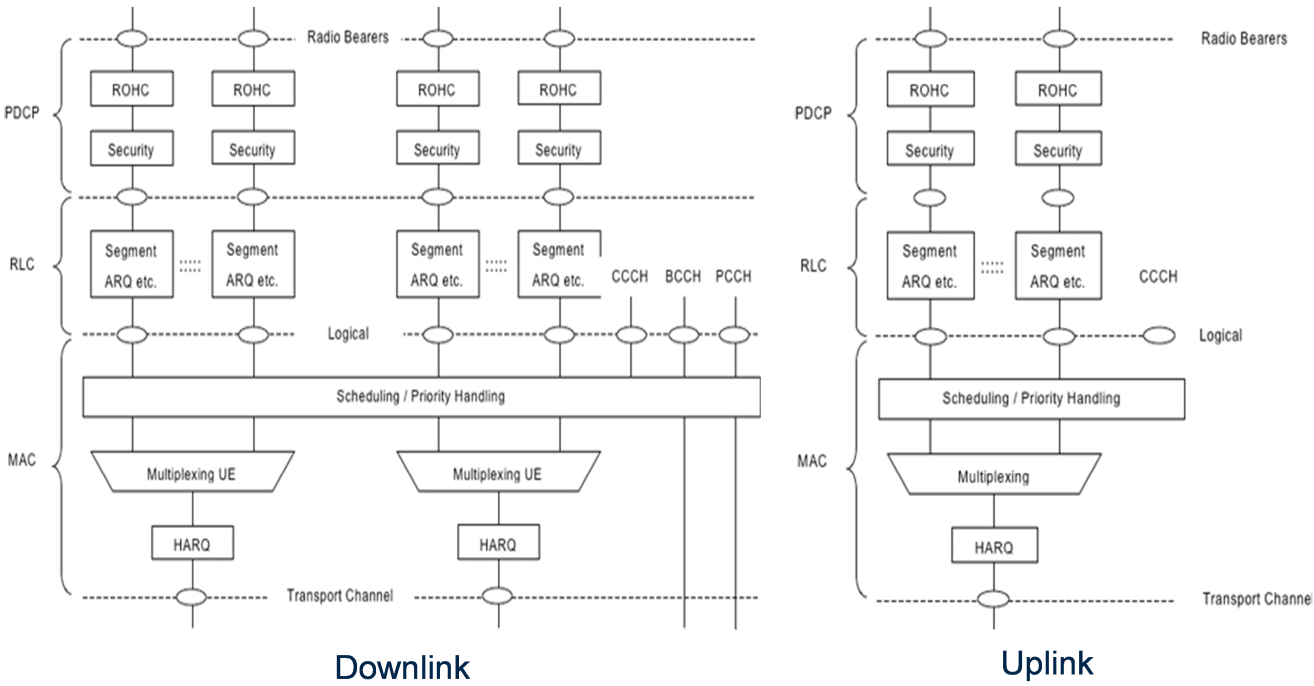

Figure 11: Uplink and Downlink Layer 2 Structures

4.1.2 *Control plane*

There is no difference in the control plane structure compared with LTE Release 8. After radio resource control (RRC) connection establishment, the configuration and/or activation of additional component carriers is performed by dedicated signaling. At intra-LTE handover, multiple component carriers can be included in the "handover command" for usage in the target cell. Idle mode mobility procedures as of LTE Release 8 equally apply in a network deploying carrier aggregation. It will be possible for a network to configure only a subset of component carriers for idle mode camping.

In order to utilize the available spectrum, devices must be able to access the control channels in the downlink and uplink frames (in addition to other reference signals). Hence, to keep backward compatibility with LTE devices, each component carrier must maintain its own control channels. On the other hand, if a service provider wants to support only LTE Advanced devices, the control channels could be reduced from one set per component carrier (of up to 20 MHz) to one set per group of aggregated component carriers (of up to 100 MHz). The option of enabling/disabling the control channels and reference signals could allow a service provider to do a progressive migration from LTE to LTE-Advanced, by controlling which spectrum bands are accessible to LTE and which to LTE-Advanced devices. A layered control signaling structure is proposed where the signaling structure depends on the assigned component carriers. In terms of scheduling, the resource assignment information (for DL and UL) can refer to resources within the same CC in which it was sent, or to resources in another CC. The first case is suitable for scenarios where the UE is configured to receive resource assignment information at each CC, and it can reliably receive it in each CC. On the other hand, the second case is suitable for scenarios where the UE is not configured to receive resource assignment information at each CC, e.g. when the bandwidth of the extra CCs is small or is only available to LTE-Advanced devices. The second case is also suitable for cases when it is not reliable to send resource assignment information in some CCs.

4.1.3 *Spectrum sharing*

Carrier/spectrum aggregation allows a service provider to offer up to 100 MHz of bandwidth to its LTE-Advanced clients by aggregating dedicated spectra in order to increase performance. However, in certain scenarios, sharing of the spectrum becomes another attractive option to achieve this objective.

Spectrum sharing could be done among radio access technologies (RATs), even though it is not currently specified by 3GPP. A service provider may offer more than one RAT to its users (e.g. LTE, HSPA, WiMAX) in a specific area. The reason for this is that the different clients of a service provider might use UEs that support different RATs. Hence, to provide coverage to all users, different RATs are deployed. It can also occur that specific UE supports several RATs.

This gives the operator the flexibility of deciding to which RAT(s) the UE should attach to maximize spectrum utilization while providing the required QoS. In this case, the requirements in terms of spectrum resources will vary spatially and temporally for each RAT. This variation/ diversity can be exploited in order to flexibly assign resources to the RATs that require them at each time and location.

In **Figure 12-a,** three operators have their own dedicated spectrum, and at the same time they share a spectrum band. In this case, LTE-Advanced could take advantage by using non-contiguous carrier aggregation (either on the same or different spectrum bands). In **Figure 12-b,** the spectrum is shared only between operators that are adjacent to the shared spectrum; in this way non-contiguous carrier aggregation is avoided which results in reduced complexity but also reduced flexibility. Effective ways to achieve spectrum sharing between several operators within the same spectrum band are required to make this type of scenario feasible, taking into account the performance and requirements of LTE-Advanced.

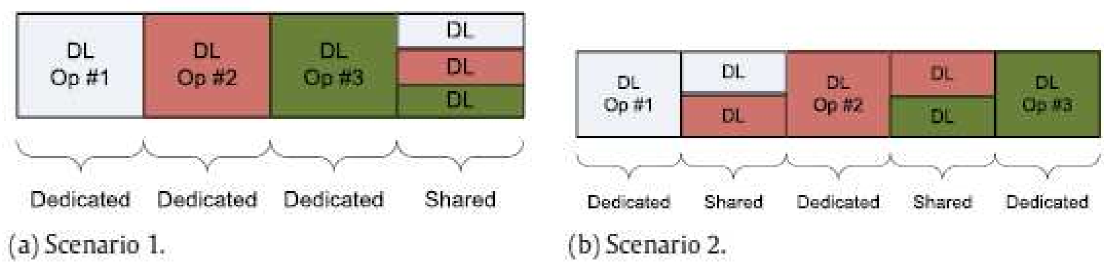

Figure 12 : Spectrum sharing scenarios.

4.2 MIMO Extension

Enhanced MIMO is considered as one of the main aspects of LTE-Advanced that will allow the system to meet the IMT-Advanced rate requirements established by the ITU-R. The majority of the MIMO technologies already introduced in LTE are expected to continue playing a fundamental role in LTE-Advanced, namely beamforming, spatial multiplexing and spatial diversity. However, further improvements in peak, cell-average, and cell-edge throughput need to be obtained to substantially increase performance.

LTE Release 8 supports MIMO antenna schemes in both downlink and uplink direction. In downlink direction up to four transmit antennas may be used whereas the maximum number of codewords is two irrespective of the number of antennas. Spatial division multiplexing (SDM) of multiple modulation symbol streams to both a single UE using the same time-frequency resource, also referred to as Single- User MIMO (SU-MIMO) and to different UEs using the same time-frequency resource, also referred to as MU-MIMO are supported. In uplink direction only MU-MIMO is used, i.e. there is only one modulated symbol stream per

UE to be received by the eNodeB, whereas multiple UEs may transmit on the same time-frequency resource.

The additional spatial dimensions introduced with MIMO in a wireless communication system can be used in three different possible ways:

- Transmit and receive diversity to improve the reliability of the transmission,
- Spatial multiplexing to boost the data rate,
- Beamforming to increase the coverage through more directive antenna patterns.

LTE-Advanced extends the MIMO capabilities of LTE Release 8 to support eight downlink antennas and four uplink antennas. As well as MIMO transmission schemes, transmit diversity and spatial multiplexing is supported in both downlink and uplink direction. Additionally, LTE-Advanced will allow MIMO technologies to be combined in what is known as extended or advanced precoding. Under the concept of advanced precoding, a novel combination of single-user beamforming with spatial multiplexing and spatial diversity as well as multi-user beamforming is meant. Single-user or multi-user beamforming can be combined with spatial multiplexing and diversity in order to simultaneously improve the range of the transmission and either obtains higher data rates (multiplexing) or a higher reliability (diversity).

The enhanced MIMO concept is conceived as an adaptive multi-mode framework where the demand of higher data rates and wider coverage is accommodated by selecting the appropriate MIMO scheme according to the current system requirement. The adaptation strategy is chosen based on all the different channel measurements that are gathered at the base station through a low rate feedback mechanism. **Figure 13** is the idea behind this concept.

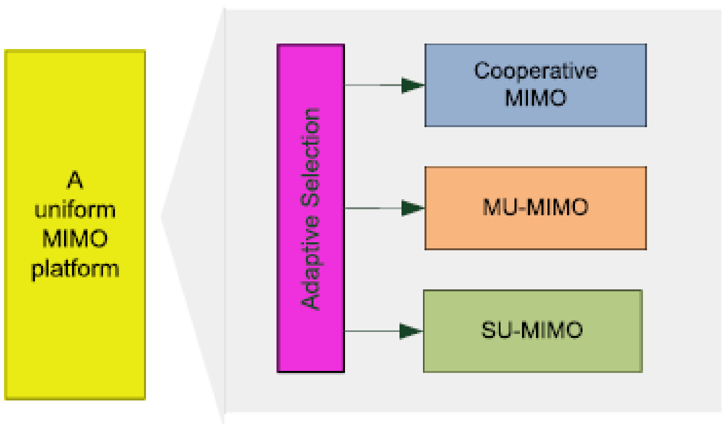

Figure 13: MIMO adaptive switching scheme.

Further, three main operating modes (**Figure 14**) are supported and each of them targets one of the improvements pursued by LTE-Advanced. These are summarize as:

- Single-User MIMO (SU-MIMO): transmit diversity and spatial multiplexing techniques can be selected for transmission in combination with beamforming. This new feature together with a higher-order MIMO (i.e. an increased number of antenna ports) make possible a substantial increase in the peak user data rates.
- Multi-User MIMO (MU-MIMO): great emphasis is placed in MU-MIMO since it offers the best complexity–performance trade-off. The flexibility of SDMA is increased by allowing a different number of streams to reach each user in order to increase the cell average data rate. SU-MIMO and MU-MIMO constitute what is called single-site MIMO.
- Cooperative MIMO: cell-edge user throughput is boosted by enabling techniques that use coordination in transmission and reception of signals among different base stations, which also helps reducing inter-cell interference. These techniques, known as Cooperative Multipoint (CoMP) transmission and reception, are another set of key technologies, and they will be covered in following section.

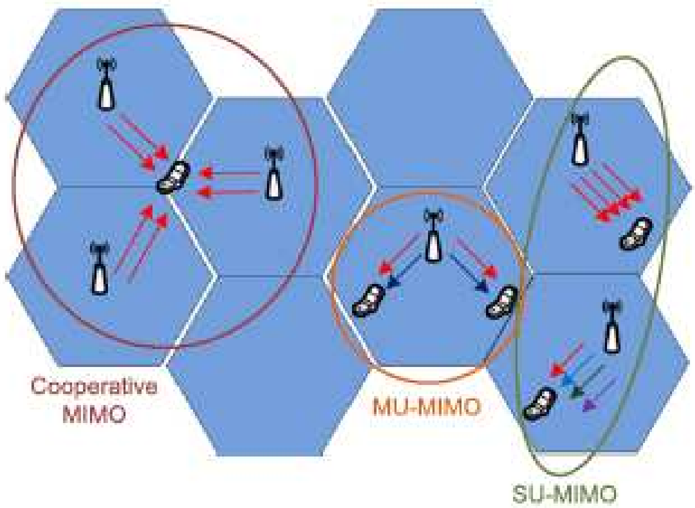

Figure 14: LTE-Advanced main MIMO modes.

4.2.1 *Downlink MIMO*

For the downlink, up to eight layers can be transmitted using an 8x8 antenna configuration, allowing for a peak spectral efficiency exceeding the requirement of 30 bit/s/Hz and implying a possibility for data rates beyond 1 Gbit/s in a 40 MHz bandwidth and even higher data rates with wider bandwidth. This calls for the introduction of additional reference signals not only for channel estimation but also for measurements such as channel quality to enable adaptive multi-antenna transmission. Backwards compatibility is considered and both additional cell-specific as well as additional UE-specific reference signals are introduced.

Operation in both open-loop and closed-loop modes is possible in combination with diversity and spatial multiplexing, i.e. feedback information may or may not be sent back by the UE depending on the radio conditions and the UE mobility. Closed-loop transmit diversity is a new feature of LTE-Advanced intended for scenarios with low mobility and low channel quality. In order to minimize intra-cell interference, MU-MIMO will be based on one or two of the following approaches: a set of fixed beams, a user-specific beam technique, or a combination of both.

User-specific beamforming is an approach that does not employ predefined precoder sets in order to provide the base station with more freedom to control or nearly null intra-cell interference. Instead, the base station may freely adjust downlink transmission weights depending on the channel conditions. These techniques are known as **non-codebook** based techniques. The idea of LTE-Advanced is to extend the single-user dedicated beamforming concept of LTE to multiple users (i.e. Space Division Multiple Access: SDMA) while supporting spatial multiplexing, and transmit diversity at the same time. The most common precoding technique for this case is zero-forcing (ZF), this can easily be implemented in practice by choosing the weight vectors as the pseudo-inverse of the composite channel matrix of the users to avoid interference among user streams. Dirty Paper Coding (DPC) is another multi-user precoding strategy based on interference pre-subtraction that achieves optimal performance in the downlink but suffers from high computational burden when the number of users is large. Precoding based on maximization of signal-to-leakage ratio (SLR) is another candidate approach to design the beamforming vectors that does not impose a restriction on the number of available transmit antennas. Any of these techniques could be used to implement user-specific beamforming.

These kind of non-codebook based precoding schemes require the terminal to make an estimate of the overall beamformed channel, as LTE already established. This is enabled through the inclusion of UE-specific reference signals that are equally precoded before transmission as the user data so that the terminal is capable of estimating the overall beamformed channel. Additionally, the number of transmit antennas used for non-codebook transmission is not constrained by the number of available cell-specific reference signals which must not interfere with each other. LTE-Advanced needs to specify new reference signals in addition to the common reference signals (CRS) defined in Release 8 of LTE. Besides in-band channel estimation, other measurements need to be considered in order to enable adaptive multi-antenna transmission. Two additional reference signals have been specified by 3GPP. They are identified in **Figure 15** and explained in the following.

- Channel state information reference signal (CSI-RS): this is used for channel sounding, i.e. estimation of the channel quality in different frequencies to those assigned to the specific UE. The signals are located in a sparse grid and require low overhead.
- UE-specific demodulation reference signal (DM-RS): this reference signal is precoded in the same way as the data when non-codebook-based precoding is applied. The grid pattern should be extended from the dual stream beamforming mode defined in Release 9 where Code Division Multiplexing (CDM) between the RS of two layers is utilized.

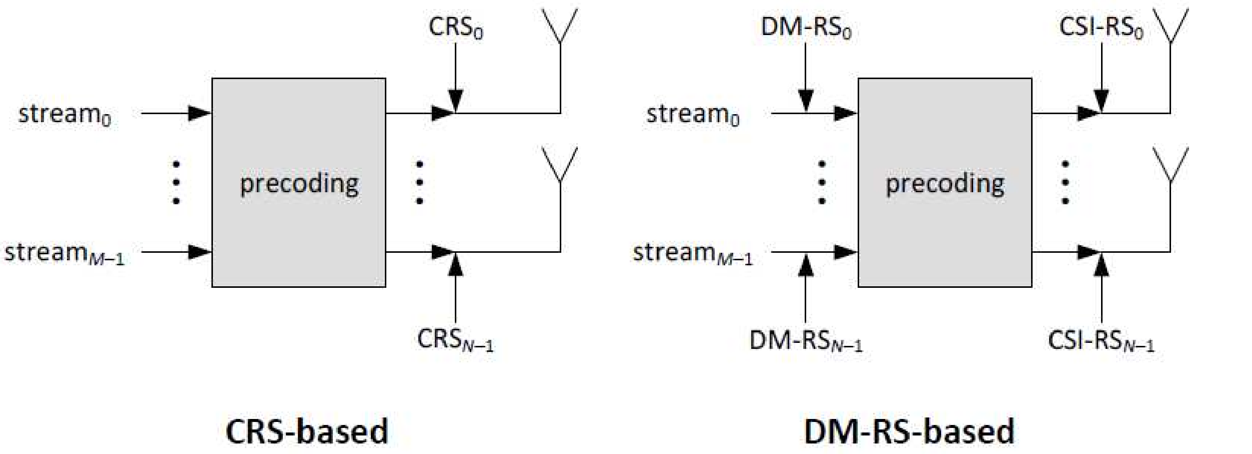

Figure 15: CRS-based versus DM/CSI-based precoding

In codebook-based precoding the transmit precoders are **chosen from predefined** sets based on the feedback received from the terminals. The support for up to eight transmit antennas has a great impact in the codebook design for closed-loop operation. The size of the codebook is large, so the terminal will need to determine the preferred precoding matrix index (PMI) among a large number of them, and the required calculation and processing will be very large. Therefore, there is an important need for optimized codebooks to reduce the computational burden and both intra-cell and inter-cell interference. Codebook based spatial multiplexing extended to 4 layers per Transport Block. **Figure 16** shows code word to layer mapping. Up to 8 transmit antennas and 8 spatial layers are supported. **Figure 17** shows an example of codebook based spatial multiplexing extended to 3 layers per Transport Block.

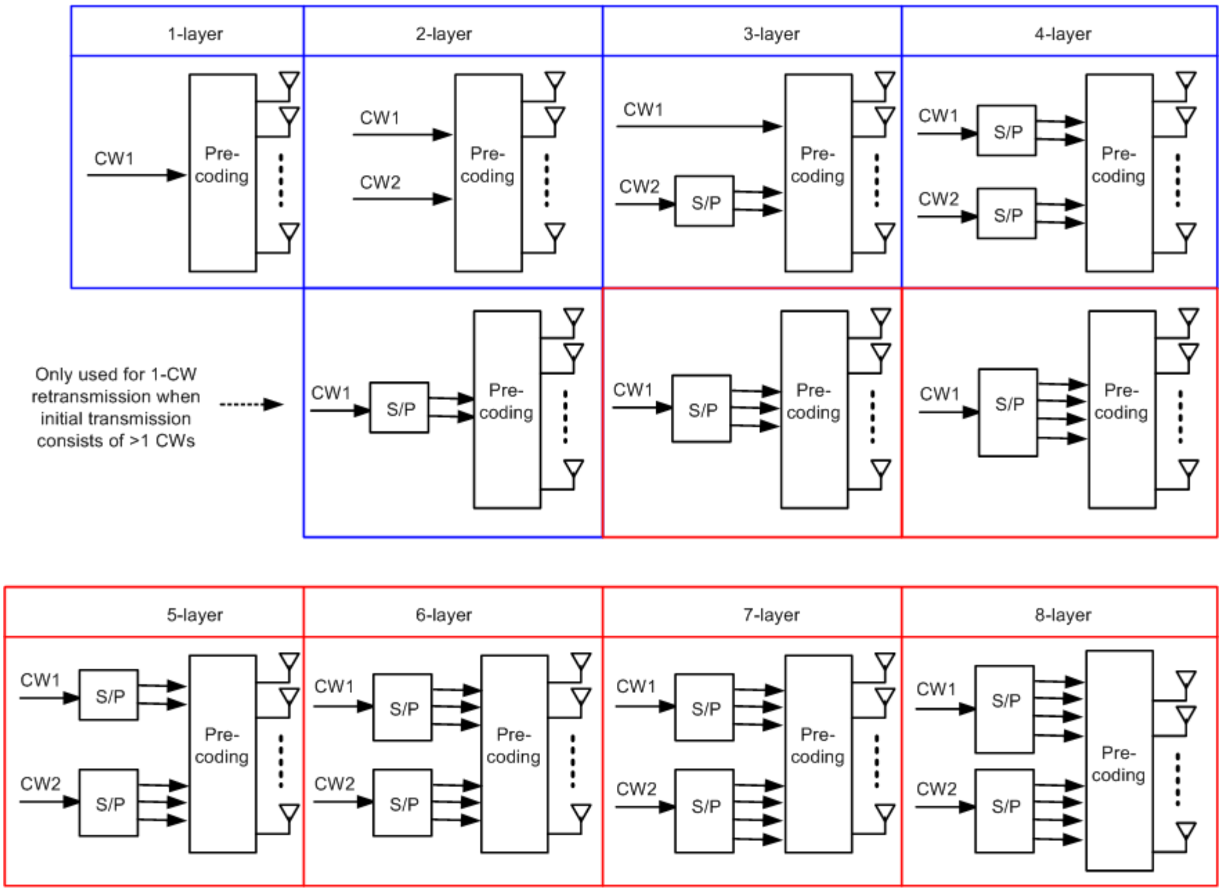

Figure 16: Codeword to layer mapping (Maximum 8 Tx Antennas)

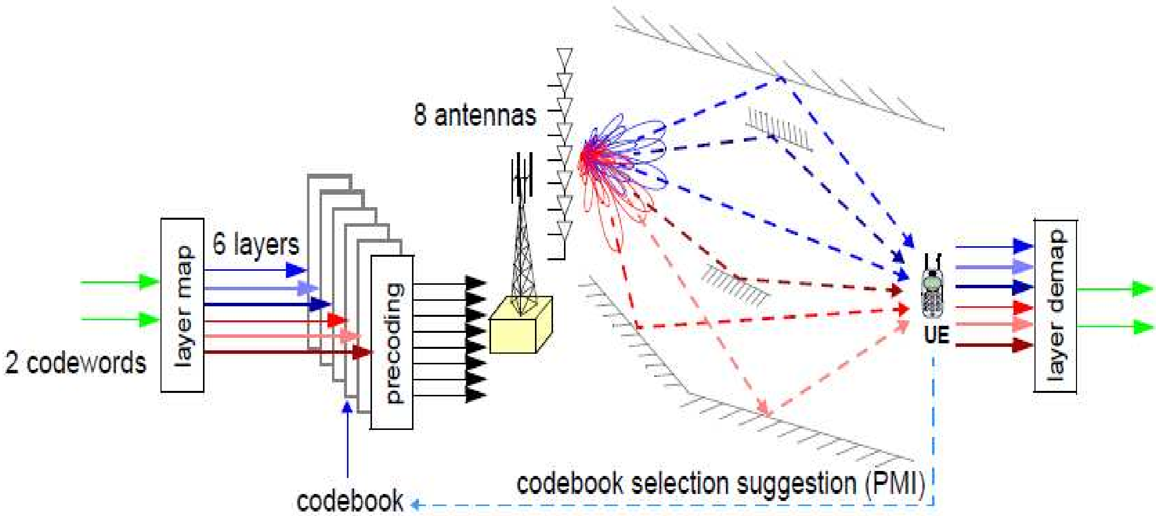

Figure 17: Codebook spatial multiplexing for 3 layers per Transport Block

Here is a summary of Downlink MIMO implementation in LTE release 8:

- Closed-loop spatial multiplexing
  - Codebook-based precoding due to CRS-based transmissions
  - Codebook subset restriction
  - Support for rank adaptation
    - Up to 2 codeword transmissions
- MU-MIMO
  - Codebook-based precoding
  - Developed under the assumption of highly correlated Tx antennas
- Dedicated beamforming
  - Non-codebook based precoding relying on DRS (Dedicated Reference Signal)
- Precoder codebook
  - Constant modulus for equal power utilization
  - Nested property for rank adaptation/override
  - Constraint alphabet (8PSK) for computation complexity reduction

Key enhancements in LTE Advanced for Downlink MIMO are:

- Up to 8 transmit antennas
  - Up to rank-8 transmissions
  - Up to 2 codewords transmissions
- Extension of non-codebook based precoding
  - Introduction of new reference signals (CSI-RS and DM-RS)
  - Commonality with MU-MIMO, CoMP
- Reuse of LTE Rel-8 transmit diversity schemes
- Enhanced MU-MIMO
  - Enabling improved precoding by virtue of DM-RS
    - Examples of precoding schemes
      - Zero Forcing based
      - SLR (Signal to Leakage Ratio) based

4.2.2 *Uplink MIMO*

The LTE-Advanced uplink provides significant improvements over LTE Release 8 in cell-edge, cell average, and peak data rates. The favorable characteristics of Single-Carrier Frequency Division Multiplex Access (SC-FDMA) of LTE Release 8 have reassured LTE-Advanced to keep the same access method, which basically consists of an additional DFT precoding phase preceding the conventional OFDMA. However, the inclusion of SU-MIMO in combination with a higher-order MIMO is seen as one of the key techniques to achieve significant technology advancement. LTE-Advanced will include spatial multiplexing of up to four layers for the uplink. With four-layer transmission, a peak uplink spectral efficiency exceeding 15 bit/s/Hz can be achieved. Many of the techniques employed for downlink spatial multiplexing already in LTE Rel-8 such as codebook based and non-codebook-based channel-dependent precoding is considered in order to not only enhance peak rates but also cell-edge data rates.

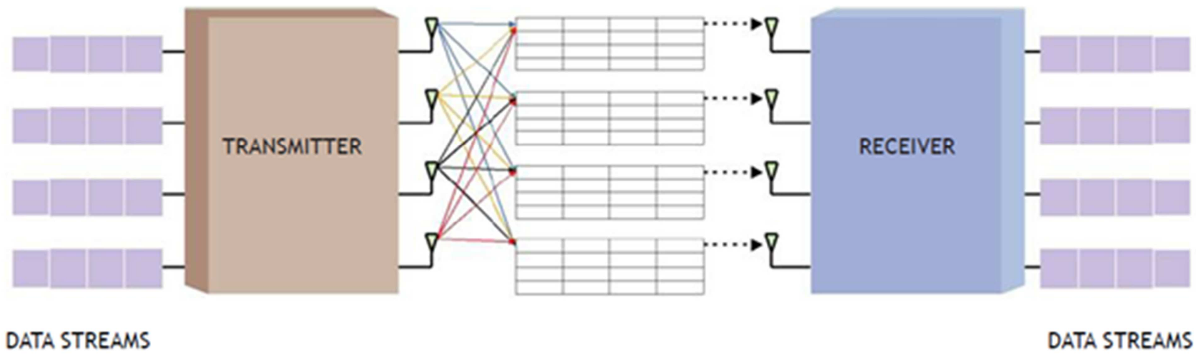

Figure 18: LTE-Advanced spatial multiplexing of up to four layers for the uplink

Codebook-based precoding plays an essential role in the uplink. Two main alternatives have been under discussion in 3GPP: wideband (WB) precoding and frequency selective (FS) precoding. The former scheme applies the same precoding vector on the whole frequency band while the latter may select a different precoder on each resource block. After multiple discussions, it has been agreed that WB precoding is more suitable since FS does not provide any gain over WB for an equal amount of feedback. Codebooks are designed so that the cubic metric (CM), a parameter defined as the cubic power of the signal of interest compared to a reference signal, is kept low. The CM is used for describing practical amplifier design. This way, the peak-to-average power ratio (PAPR) is more emphasized in the uplink and the favorable SC-FDMA properties are maintained. Dynamic rank adaptation is also introduced in Release 10 to obtain further performance improvements. Link Adaptation is in addition to some advanced receiver implementation such as Successive Interference Cancellation (SIC). Optional layer shifting (LS) in combination with HARQ-ACK spatial bundling is also available. Further, instead of associating one HARQ process per layer, two layers could share a single HARQ process by generating a single ACK for both layers.

With LTE-Advanced a scheduled UE may transmit up to two transport blocks. Each transport block has its own modulation and coding scheme (MCS level). Depending on the number of transmission layers, the modulation symbols associated with each of the transport blocks are mapped onto one or two layers with the same principle as for LTE Release 8 downlink spatial multiplexing. The transmission rank can be adapted dynamically. Different codebooks are defined depending on the number of layers that are used. Furthermore different precoding is used depending on whether two or four transmit antennas are available. In contrast to the LTE Release 8 downlink scheme, whereas several matrices for full-rank transmission are available, only the identity precoding matrix is supported in LTE-Advanced uplink direction. For uplink spatial multiplexing with two transmit antennas, 3 - bit precoding codebook is defined and for uplink spatial multiplexing with four transmit antennas, 6-bit precoding codebook is used.

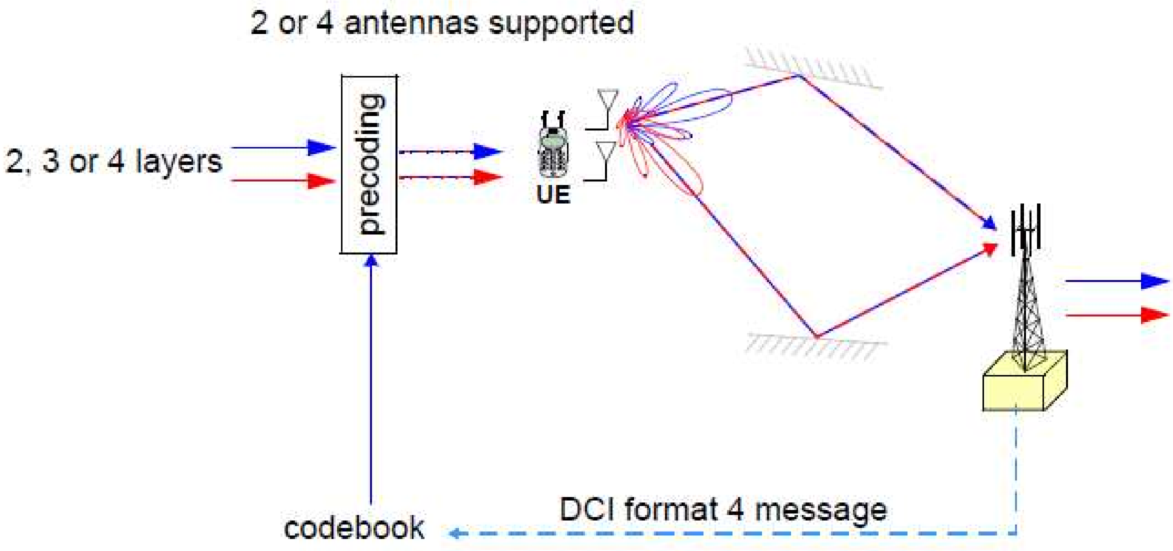

Figure 19: Uplink support for up to 4 layers, 2 per codeword with codebook based precoding

For FDD and TDD, precoding is performed according to a predefined codebook. If layer shifting is not configured, precoding is applied after the layer mapping. If layer shifting is configured, precoding is applied after the layer shifting operation.

For uplink transmit diversity those UEs with multiple transmit antennas, a so-called uplink Single Antenna Port Mode is defined. In this mode the LTE-Advanced UE behavior is the same as the one with a single antenna from eNodeB’s perspective and it is always used before the eNodeB is aware of the UE transmit antenna configuration. In the transmit diversity scheme, the same modulation symbol from the uplink channel is transmitted from two antenna ports, on two separate orthogonal resources.

Following are the major feature enhancements of LTE-Advanced for Uplink MIMO:

- Introduction of spatial multiplexing
  - Layer shifting: FFS
    - HAR-ACK spatial bundling with layer shifting
    - No HARQ-ACK spatial bundling and no layer shifting
- Codebook-based precoding
  - Rank-dependent codebook
  - Cubic Metric (CM) Preserving/Friendly
  - No nested property
- Precoded DM-RS based transmissions
- Introduction of transmit diversity
  - PUCCH transmit diversity: Spatial Orthogonal Resource Transmit Diversity (SORTD)

4.3 Uplink Multiple Access Extension

The uplink transmission scheme of LTE-Advanced has been maintained to a large extent, i.e. single carrier – frequency division multiple access (SC-FDMA) is used, which is a discrete fourier transformed (DFT) precoded orthogonal frequency division multiple access (OFDMA) scheme. The transmission of the physical uplink shared channel (PUSCH) uses DFT precoding in both MIMO and non-MIMO modes. However the following enhancements have been incorporated into the system:

- Control-data decoupling
- Non-contiguous data transmission with single DFT per component carrier

Control-data decoupling

In LTE Release 8 a UE only uses physical uplink control channel (PUCCH) when it does not have any data to transmit on PUSCH. I.e. if a UE has data to transmit on PUSCH, it would multiplex the control information with data on PUSCH. This is not longer valid in LTE-Advanced, which means that simultaneous PUCCH and PUSCH transmission is possible in uplink direction.

Non-contiguous data transmission with single DFT

The LTE Release 8 uplink scheme SC-FDMA differs from downlink schemes, as an additional DFT is used in the transmission chain that transforms the modulation symbols into the frequency domain. In Release 8 localized SC-FDMA is allowed only, i.e. in uplink direction only consecutive subcarriers are transmitted. This is the essential advantage of the scheme, since it reduces the peak to average ratio of the transmitted signal and consequently allows more efficient power amplifier implementation. LTE-Advanced extends the uplink transmission scheme by allowing clustered SC-FDMA, i.e. the uplink transmission is not anymore restricted to the use of consecutive subcarriers, but clusters of subcarriers may be allocated. This allows uplink frequency selective scheduling and consequently will increase the link performance. However the peak to average ratio of the transmission signal will be increased compared with the localized scheme of LTE Release 8. **Figure 20** provides the uplink block diagram of the transmission chain.

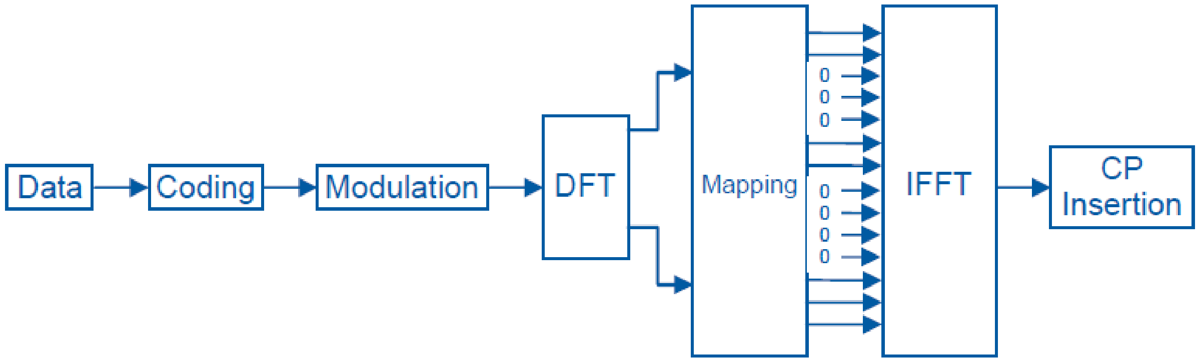

Figure 20: Block diagram for clustered SC-FDMA in uplink LTE-Advanced

In the uplink, LTE uses DFT-precoded OFDM. LTE Advanced there is one DFT per component carrier, supporting contiguous and frequency-non-contiguous resource allocation on each CC:

- Within CC
    - Efficient radio resource assignment with relaxed peak to-average power ratio (PAPR) requirement
    - Single-carrier FDMA (DFTS-OFDM) based multiple access similar to that for Rel-8 LTE
    - Non-contiguous data transmission with single DFT (clustered DFTS-OFDM)
- Among CCs
    - Priority to easy resource block assignment, i.e., implementation at the cost of increase in PAPR
    - N-times clustered DFTS-OFDM

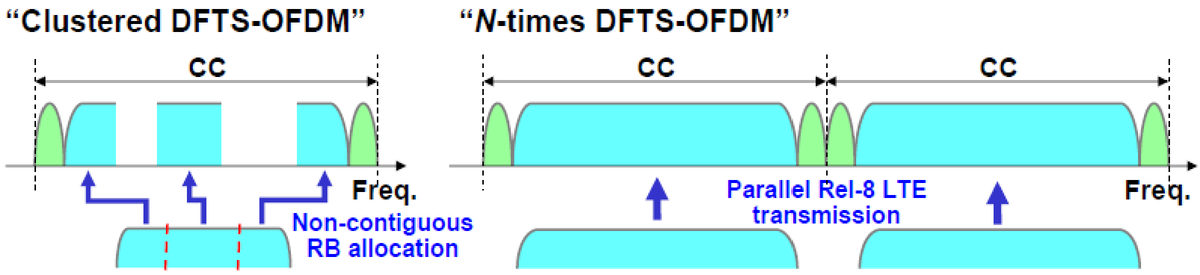

Figure 21: Extension of Uplink Multiple Access

4.4 Coordinated Multiple Point transmission and reception (CoMP)

Coordinated multi-point transmission and reception (CoMP) is a DL/UL orthogonalization technique to improve system capacity and cell edge user throughput. The basic idea behind CoMP is to apply tight coordination between the transmissions at different cell sites, thereby achieving higher system capacity and, especially important, improved cell-edge data rates. Two kinds of architecture can be distinguished with respect to the way this information is made available at the different transmission points: centralized and distributed CoMP. **Centralized** control is based on remote radio equipment (RRE) architecture and distributed control is based on independent eNB architecture. Both types of architecture can be combined with any of the different CoMP transmission schemes although the degree of complexity to implement them may vary from one scheme to the other.

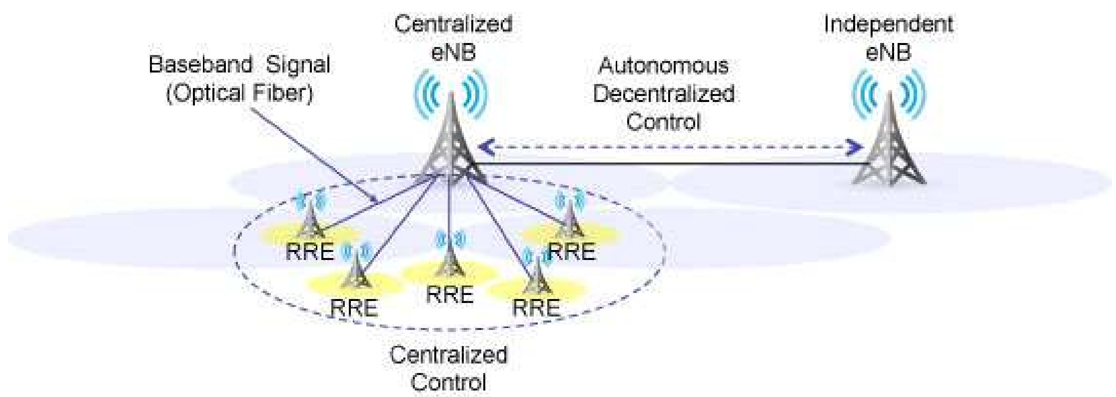

Figure 22: Extension of Uplink Multiple Access

In the approach with independent eNB architecture, CoMP is performed by signaling between eNBs. This technique can utilize legacy cells, but the disadvantage is signaling delay and other overheads. In the second approach with RRE technique, the eNB can centralize and control all the radio resource by transmitting baseband data directly between eNB and RREs on optical fiber connections. There is little signaling delay or other overheads in this technique, and Intra-cell radio resource control is relatively easy. However, CAPEX on optical fibers is not negligible, and centralized eNB must be able to accept higher load according to the number of RREs.

Coordination schemes can be divided into two categories, used either alone or in combination:

- Dynamic scheduling coordination between multiple cells
- Joint transmission/reception from multiple cells

In the former case, CoMP can to some extent be seen as an extension of the inter-cell interference coordination part present already in LTE Rel-8. In LTE-Advanced, the coordination can be in terms of the scheduling at the different cell sites, thereby achieving an even more dynamic and adaptive inter-cell interference coordination. Alternatively, or as a complement, transmissions can be carried out to a mobile terminal jointly from several cell sites, thereby not only reducing the interference but also increasing the received power. The transmission from the cell sites can also take the instantaneous channel conditions into account, thereby achieving multi-cell beam-forming or precoding gains. The channel-estimate required for demodulation of the downlink transmission at the terminal can basically be obtained using either cell-specific or UE-specific reference signals.

CoMP is applied in the downlink by performing a coordinated transmission from the base station, whereas interference in the uplink can be reduced by means of a coordinated reception in eNBs. Most of the CoMP approaches share the requirement of needing some scheduling information regarding the users at the different base stations that must be shared among them. This means that very-low-latency links are required so that information can be exchanged between coordinated nodes.

4.4.1 *Downlink CoMP*

In the downlink, two main CoMP transmission techniques are envisioned: cooperative scheduling/beamforming and joint processing. Their main difference lies in the fact that in the former scheme it is only one eNB that transmits data to the UE, although different eNBs may share control information. In the latter scheme, many eNBs transmit data simultaneously to the same UE. In the uplink, however, only a coordinated scheduling approach is envisioned.

- Joint processing (JP CoMP)
  - Data is available at each at each cell in CoMP cooperating set
    - Joint transmission: data transmitted from multiple point at a time
    - Fast Cell Selection (FCS) : data transmitted from one point at a time
- Coordinated Scheduling/Beamforming (CS/CB CoMP)
  - Data is only available at serving cell but user scheduling/BF decisions are made with coordination among cells

Joint processing:

In the category of joint processing (JP), data intended for a particular UE are jointly transmitted from multiple eNBs to improve the received signal quality and cancel interference. Different site location means inherent low correlation; hence, even though this approximation gives an upper bound for the system capacity, a high potential gain may be achievable. Two different methods are being studied for the JP scheme: joint transmission and dynamic cell selection. Although data are indeed transmitted from several sites, the former scheme does it simultaneously while the latter uses a fast cell selection approach and only one of them transmits data at a time. This advanced pair of techniques is particularly beneficial for cell-edge throughput and is anticipated to be the dominant application of CoMP. **Figure 23** shows a simplified scheme of both techniques. In both cases user data need to be shared among base stations so a very fast link interconnecting them is required, although the complexity of the signal processing is higher in the joint transmission scheme.

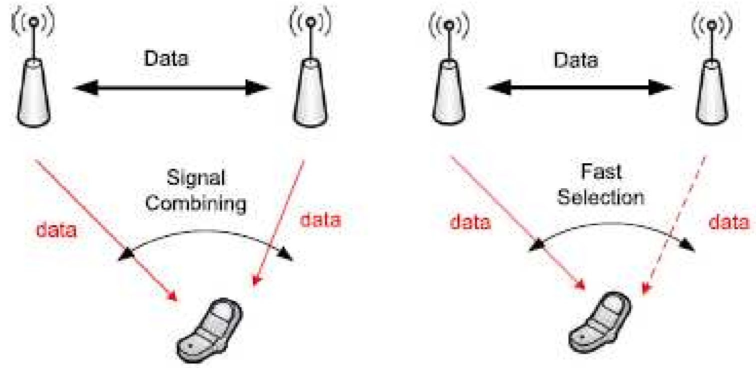

Figure 23: Joint processing: joint transmission (left) and dynamic cell selection (right)

Coordinated scheduling/beamforming:

Coordinated scheduling/beamforming (CS/CB) is characterized by the fact that each UE is served by a single cell known as the ''anchor cell''. However, precoding at each base station to enable beamforming is coordinated to improve the sum throughput and reduce interference. **Figure 24** depicts an architectural example of this transmission scheme. The feedback design should be enhanced to give support for this transmission strategy. The scheduler at each eNB makes its decisions independently but additional information about other user's channel conditions is necessary in order to perform a more optimal scheduling and beamforming.

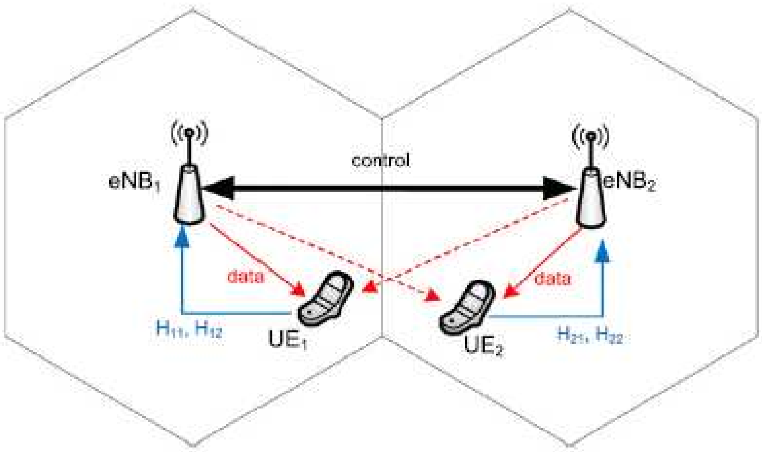

Figure 24: Coordinated scheduling/beamforming approach

4.4.2 *Uplink CoMP*

Uplink CoMP utilizes geographically separated antennas for signal reception from UE, and scheduling decisions are coordinated by multiple cells to control interference from each other. UE is not aware of multi-cell reception of its signal, so that impact on radio interface specification is at minimal. Implementation of Uplink CoMP largely depends on scheduler and receiver in the cells.

In the uplink the CoMP scheme, aimed at increasing the cell-edge user throughput, implies the reception of the signal transmitted by UEs at multiple and geographically separated points, as **Figure 25** shows. These points are nothing but the set of coordinating eNBs assigned to each UE. Generally speaking, the terminal does not need to be aware of the nodes that are receiving its signal and what processing is carried out at these reception points. This is all an implementation issue, so CoMP reception is expected to have limited impact on the specifications, and no major change in the radio interference should be required. Nonetheless, scheduling decisions can be coordinated among cells, and some specification impact may be brought from this fact. There are different schemes that can be used at multiple reception points to combine the received signals. Maximum Ratio Combining (MRC), Minimum Mean Square Error Combining (MMSEC), and Interference Rejection Combining (IRC) are examples of techniques that extract the transmitted information from the received signal.

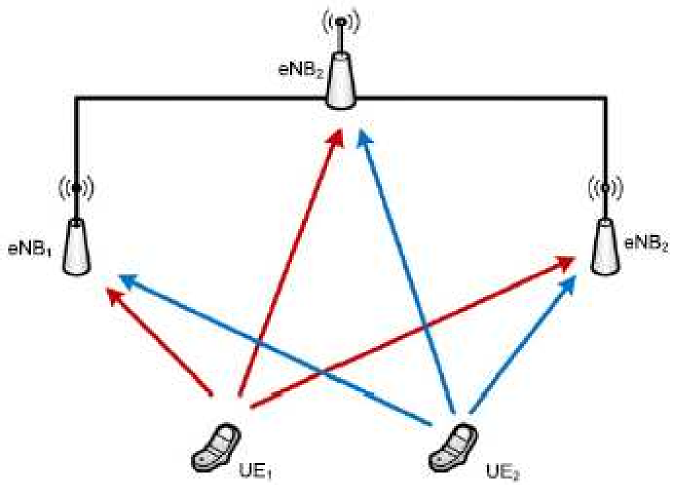

Figure 25: Uplink CoMP scheme

Uplink CoMP can be summarized as:

- Uplink signal is received at multiple points
- Scheduling decisions can be coordinated among cells to control interference

4.5 Advanced Relaying

To reduce the transmitter-to-receiver distance for achieving higher data rates, a denser infrastructure is required. The concept of Relay Node (RN) has been introduced to enable traffic/signaling forwarding between eNB and UE to improve the coverage, group mobility, cell edge coverage, and to extend coverage to heavily shadowed areas in the cell or areas beyond the cell range. It provides throughput enhancement especially for the cell edge users and offers the potential to lower the CAPEX and OPEX by keeping the cell sizes relatively large (**Figure 26**).

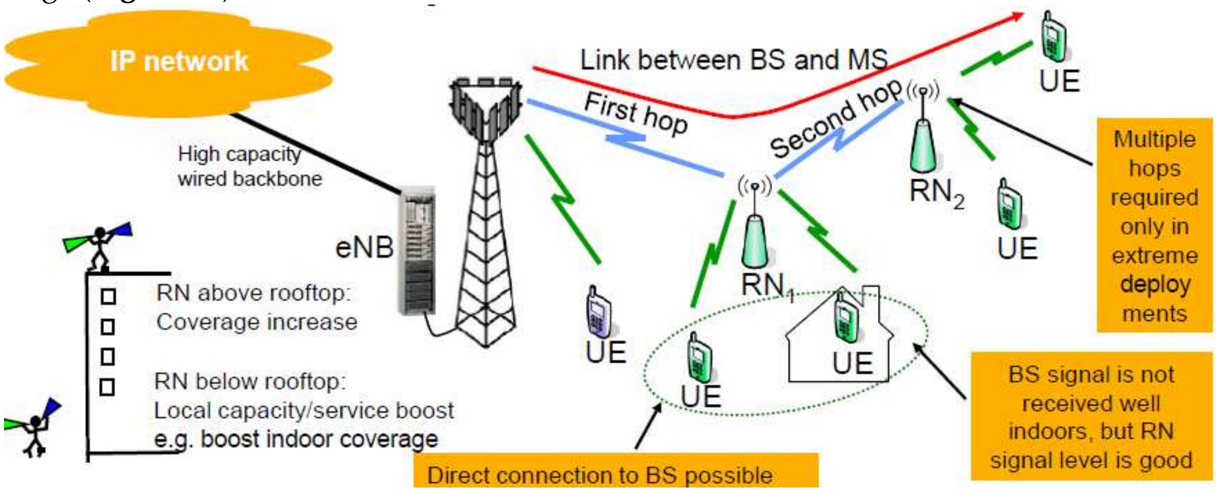

Figure 26: Relay Node Deployment

Relays can be classified according to the layers in which their main functionality is performed:

- A Layer 1 (L1) relay is also called a repeater
- A Layer 2 (L2) relay is also called decode and forward
- A Layer 3 (L3) or higher-layer relay can be thought of as a wireless eNB that uses a wireless link for backhaul instead of a wired and expensive link.

The simplest relaying is the ***Layer 1 relaying***, that is, the usage of repeaters. Repeaters receive the signal, amplify it and retransmit the information thus covering black holes inside cells. Terminals can make use of the repeated and direct signals. However, in order to combine constructively both signals there should be a small delay, less than the cyclic prefix, in their reception.

The ***Layer 2 Relay*** performs the decode-and-forward operation and has more freedom to achieve performance optimization. Data packets are extracted from RF signals, processed and regenerated and then delivered to the next hop. This kind of relay can eliminate propagating the interference and noise to the next hop, so it can reinforce signal quality and achieve much better link performance.

Finally, ***Layer 3 relaying*** is conceived to use the LTE radio access in the backhaul wireless connecting one eNB with another eNB that behaves as a central hub. This anchor eNB routes the packets between the wired and wireless backhaul, acting like an IP router. Layer 3 relaying solution let the relay perform the same functions as normally handled by the base station, e.g. hybrid-ARQ retransmissions, scheduling, and mobility functions. In essence, the relay is, from a functional perspective, a base station and therefore there is no need to define new functions for mobility.

Due to the relay transmitter causing interference to its own receiver, simultaneous eNodeB-to relay and relay-to-UE transmissions on the same frequency resource may not be feasible unless sufficient isolation of the outgoing and incoming signals is provided. Similarly, at the relay it may not be possible to receive UE transmissions simultaneously with the relay transmitting to the eNodeB. One way to handle the interference problem is to operate the relay such that the relay is not transmitting to terminals when it is supposed to receive data from the donor eNodeB, i.e. to create "gaps" in the relay-to-UE transmission. These "gaps" during which terminals (including Rel-8 terminals) are not supposed to expect any relay transmission can be created by configuring MBSFN subframes.

4.6 Heterogeneous Networks

The evaluation cases for heterogeneous network deployments have been included in LTE Release 10. There are multiple technologies that can be used for the interference coordination based on LTE Release 8 specification, e.g. HeNB power control and escape carrier or using Carrier Aggregation of LTE Release 10. LTE Release 10 includes one new interference coordination technology based on coordinated muting of the transmission of overlapping cells. This technology is called TDM eICIC (Time Domain enhanced Inter-Cell Interference Coordination). Part of the transmitted signal is muted by sending almost blank sub-frames that allows other eNBs to transmit with lower inter-cell interference. TDM eICIC needs time synchronization between the macro and femto layers, a pre-condition that could be difficult to guarantee with respect to HeNBs deployed by the users. Simpler frequency domain methods are then more likely to be used in case the operator's frequency and deployment plans allow.

4.7 Self-Organizing and Optimization Network (SON)

LTE development is not only focusing on air interface performance enhancements. Cost of deployment and operation can be decreased with self-organizing and optimization (SON) technologies. Automatic Neighbour Relation (ANR) and Minimization Drive Test (MDT) technologies have been developed to enable automatic configuration, optimization of handovers, as well as other radio resource management parameters. Moreover, other SON technologies are also in the process of being developed, e.g. for automated fault recovery and energy saving for complex deployments. Some deployment concepts and network architectures are common for HSPA and LTE: Home base stations are a way to provide reliable and secure mobile broadband services in home and office environments. Local Break Out solutions (LIPA and SIPTO) decrease cost of transport and enable lower end-to-end latency for distributed services. Given the fact that a majority of mobile broadband networks fall under the domain of multi-radio networks, common solutions for HSPA+ and LTE-Advanced translate into lower cost for operators and seamless service experience for end users.

4.8 HNB and HeNB mobility enhancements

TBD

5. Conclusion

The evolution of LTE, often referred to as LTE-Advanced (LTE Release 10 and beyond), will incorporate additional technology components to further enhance the performance beyond the IMT-Advanced requirements while maintaining backwards compatibility with earlier releases of LTE. The technology components being considered for LTE-Advanced include carrier aggregation, both for contiguous and non-contiguous spectrum to support bandwidths up to 100 MHz as well as enhanced multiple antenna transmission with up to eight layers in the downlink and up to four layers in the uplink. In addition to relaying and repeater solutions to enhance coverage and cell edge data rates, an evolution of the inter-cell interference coordination in the form of coordinated multipoint transmission/reception is yet another technology to enhance performance. Now all the identified components for LTE Advanced are increasing the design complexity of Mobile handsets and base stations.

6. References

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