Next generation LTE, LTE-Advanced

Next generation LTE, LTE-Advanced or LTE Rel-10 is the next step in radio access technology.

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Whatever the name – next generation LTE, LTE-Advanced or LTE Rel-10 – the next step in LTE evolution allows operators to introduce new technologies without putting existing investments at risk.

LTE radio access technology is continuously evolving to meet the requirements of regulators, operators and users. The first fully commercial and operational 4G mobile broadband systems, currently being deployed, are based on the first release of LTE, 3GPP Rel-8, which was finalized in 2008.

Rel-9, finalized at the end of 2009, added support for broadcast/multicast services, positioning services, and enhanced emergency call functionality, as well as enhancements for downlink dual-layer beam forming.

Today, the main focus of 3GPP is the next generation of LTE evolution, Rel-10, often referred to as LTE-Advanced. Rel-10 further extends the performance and capabilities of the LTE radio access technology, and meets all of the requirements for IMT-Advanced as defined by ITU[1, 2].

In October 2010, ITU completed the assessment of submissions for global 4G mobile wireless broadband technology, LTE Rel-10 (submitted by 3GPP) was one of two technologies accorded the official designation of IMT-Advanced.

This article provides a brief introduction to IMT-Advanced, followed by a description of the extensions to LTE introduced as part of 3GPP Rel-10. It concludes with system-level results that illustrate the ability of LTE Rel-10 to fulfill and even surpass the IMT-Advanced requirements.

ITU and IMT-Advanced

IMT-Advanced is the term used by ITU for radio access technologies beyond IMT-2000. An invitation to submit candidate technologies for IMT-Advanced was issued by ITU in 2008[1]. Together with this invitation, ITU defined a set of requirements to be fulfilled by any IMT-Advanced candidate technology[2], some of which are shown in **Table 1**.

Anticipating the invitation from ITU, 3GPP initiated a study in March 2008 on LTE-Advanced, with the task of defining requirements and investigating potential technology components for the LTE evolution. Ericsson was very active in the 3GPP study, which was completed in 2009 and formed the basis for the 3GPP Rel-10 work on LTE[5].

LTE Rel-10

LTE-Advanced is not a new radio access scheme distinct from LTE, but simply the evolution of LTE, providing improved performance and service capabilities. LTE Rel-10 includes all of the features of Rel-8/9 and several new ones, the most important of which are:

- carrier aggregation;
- enhanced multi-antenna support; and
- improved support for heterogeneous deployments, and relaying.

Carrier aggregation

The first releases of LTE provided extensive support for deployment in spectrum allocations of various characteristics, with transmission bandwidths ranging from 1.4MHz up to 20MHz in both paired and unpaired bands. In Rel-10, the transmission bandwidth can be further extended with so-called *carrier aggregation* (CA)[3] where multiple *compo-*

BOX A Terms and abbreviations

3GPP	3rd Generation Partnership Program
4G	4th Generation mobile wireless standards
ARQ	automatic repeat request
BS-to-RN	base station to relay node
CA	carrier aggregation
CSG	closed subscriber group
CSI	channel-state information
DFT	Discrete Fourier Transform
DL-related	downlink-related
E-UTRA	Evolved Universal Terrestrial Radio Access
FDD	frequency-division duplex
HARQ	hybrid ARQ
HSPA	High-Speed Packet Access
ICIC	inter-cell interference coordination
IMT	International Mobile Telecommunications
InH	indoor hotspot
ITU	International Telecommunication Union
ITU-R	ITU Radiocommunication
LTE	Long-Term Evolution
MAC	Medium Access Control
MBSFN	Multicast-Broadcast Single Frequency Network
OFDM	orthogonal frequency-division multiplexing
PHY	physical layer
RF	radio frequency
RLC	Radio Link Control
RMa	rural macro
TDD	time-division duplex
UE	user equipment
UL-related	uplink-related
UMa	urban macro
UMi	urban micro
WCDMA	Wideband Code Division Multiple Access

Table 1: Requirements and LTE fulfillment

TYPE	IMT-ADVANCED REQUIREMENT	LTE REL-8	LTE REL-10
Transmission bandwidth	At least 40 MHz	up to 20 MHz	Up to 100 MHz
Peak spectral efficiency			
Downlink	15 bps/Hz	16 bps/Hz	16.0 [30.0]* bps/Hz
Uplink	6.75 bps/Hz	4 bps/Hz	8.1 [16.1]** bps/Hz
Latency			
Control plane	Less than 100 ms	50 ms	50 ms
User plane	Less than 10 ms	4.9 ms	4.9 ms

* Value is for a 4x4 antenna configuration. Value in parentheses for 8x8
** Value is for a 2x2 antenna configuration. Value in parentheses for 4x4

nent carriers are aggregated and jointly used for transmission to/from a single mobile terminal, as illustrated in **Figure 1**. Up to five component carriers can be aggregated, allowing for transmission bandwidths up to 100MHz. Backward compatibility is ensured as each component carrier conforms with the Rel-8 carrier structure. Consequently, to a Rel-8/9 terminal, each component carrier will appear as an LTE Rel-8 carrier, whi le a carrier aggregation-capable Rel-10 terminal can exploit the total aggregated bandwidth, thus achieving higher data rates.

In general, a different number of component carriers can be aggregated for the uplink and downlink. We can generally expect that a terminal will have different aggregation capabilities in the uplink and downlink directions.

There are three cases in terms of the frequency location of the different component carriers:

- **intra-band aggregation with contiguous carriers (#2 and #3 in Figure 1);**
- **inter-band aggregation (#1 and #4 in Figure 1); and**
- **intra-band aggregation with non-contiguous carriers (#1 and #2 in Figure 1).**

Aggregating non-adjacent component carriers means that the fragmented spectrum can be utilized, which in turn allows operators to provide high data rate services based on the availability of a wide overall bandwidth, even without a single wideband spectrum allocation.

From a baseband perspective, there is no difference among the three different aggregation alternatives, with LTE Rel-10 supporting them all. However, the complexity of the RF implementation varies greatly, with the first case being the least complex. As a result, while spectrum aggregation is supported by the basic Rel-10 specifications, implementation will be strongly constrained and will include specification of only a limited number of aggregation scenarios; only the most advanced terminals will support aggregation over a dispersed spectrum.

Figure 2 shows how scheduling »

FIGURE 1 **Carrier aggregation in LTE Rel-10.**

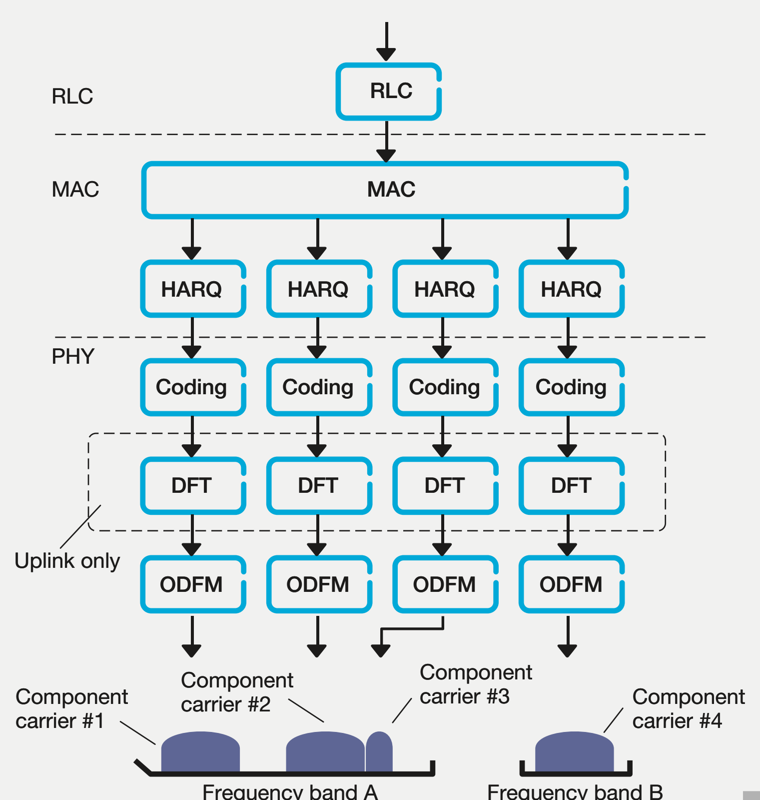
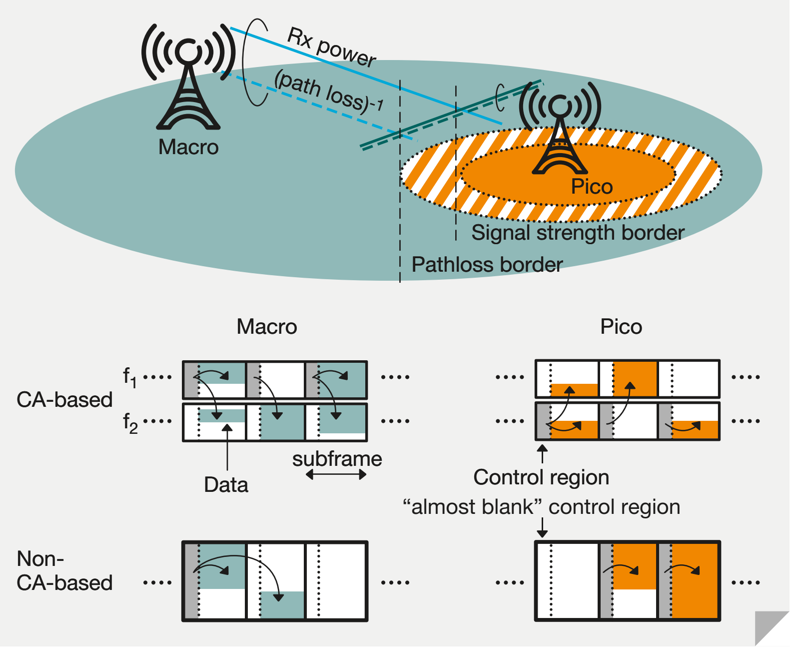


FIGURE 2 Heterogeneous deployment with a macro cell overlaying multiple pico cells.



and hybrid-ARQ retransmissions are handled independently for each component carrier. As a baseline, control signaling is transmitted on the same component carrier as the corresponding data. However, as an alternative, it is possible to use *cross-carrier scheduling* where the scheduling information is transmitted to the terminal on a different component carrier to the corresponding data transmission. This option could. for example, be used for heterogeneous deployments, as described later in this article.

To reduce terminal power consumption, a carrier-aggregation-capable terminal as baseline receives on one component carrier, the *primary component carrier*. Reception of additional *secondary component* carriers can be rapidly turned on or off in the terminal by the base station through MAC signaling. Similarly, in the uplink, feedback signaling is transmitted on the primary component carrier and secondary carriers are enabled when necessary for data transmission.

Enhanced multi-antenna support

Downlink spatial multiplexing in Rel-10 is enhanced to support up to eight transmission layers, together with an enhanced reference-signal structure. Relying on cell-specific reference signals for higher order spatial multiplexing is less attractive, as the reference-signal overhead is not proportional to the instantaneous transmission rank, but rather to the maximum supported transmission rank. Rel-10, therefore, introduces extensive support of UE-specific reference signals for demodulation of up to eight layers. In addition, feedback of channel-state information (CSI) is based on a separate set of reference signals – CSI reference signals. *CSI reference signals* are relatively sparse in frequency but regularly transmitted from all antennas at the base station, while the UE-specific reference signals are denser in frequency but only transmitted when data is transmitted on the corresponding layer.

Separating the reference-signal structures supporting demodulation and channel-state estimation helps to reduce reference-signal overhead, especially for high degrees of spatial multiplexing, and allows for implementation of various beam-forming schemes.

LTE Rel-10 also introduces the possibility for uplink spatial multiplexing with up to four layers, essentially extending the uplink peak data rates by a factor of four compared to earlier LTE releases.

Improved support for heterogeneous deployments

Increased use of mobile broadband has shifted the focus from theoretical peak rates to practical data rates experienced by users. The actual rate is dependent on several deployment factors, such as the terminal-to-base-station distance. Since the ability to improve link performance or increase transmission power is limited, a denser infrastructure is required, in many cases to support very high data rates. A denser network also directly increases the system capacity, or in other words, the total amount of traffic that can be handled by the network.

Straightforward densification of an existing macro network is one way of achieving the required density. However, for areas where users are highly clustered, a potentially more attractive approach is to complement a macro-cell layer providing basic coverage with additional low-output-power pico cells where needed, as shown in Figure 2. The result of such a strategy is a *heterogeneous deployment* with two or more overlaying cell layers.

The idea of multiple cell layers is in itself not new; it is a deployment strategy and not a technology component. As such, heterogeneous deployments are possible with LTE Rel-8 and Rel-9. However, Rel-10 provides additional features that improve the support for this type of deployment.

In a heterogeneous deployment with cells of very different output power, cell association (which cell a terminal should connect to) plays an important role. From an uplink data-rate perspective, connecting to the cell with the lowest path loss results in a higher data rate at a given transmit power. This is opposed to the traditional approach of connecting to the cell with the best downlink signal quality. Determining the best cell for downlink association depends on the load: at low load, connecting to the cell with the strongest received downlink offers the highest data rates, while at high loads, connecting to the low-power node may be preferable as it enables resource reuse among low-power nodes.

Cell association in a heterogeneous

deployment is therefore a non-trivial task when overall network performance is taken into account. Nevertheless, a cell association strategy not only focusing on maximizing the downlink signal quality can lead to new interference situations in the network. Essentially, the uplink coverage area can be larger than the downlink coverage area, implying that there is a region around the low-power node (illustrated by the dashed area in Figure 2) where downlink transmission from the low-power node to a terminal is subject to strong interference from the macro cell.

The signal-to-interference ratio experienced by the terminal at the outermost coverage area of the low-power node is a function of the difference in output power between the high-power macro and the low-power node, and can be significantly lower than what is experienced in a more homogeneous deployment.

For the data part of a subframe, this is not a serious problem as the *inter-cell interference coordination* (ICIC) mechanism presented as early as in Rel-8 can be used to more or less dynamically coordinate the resource usage between the cell layers and avoid overlapping resource usage. The cell layers can exchange information about which frequencies they intend to schedule transmissions on in the near future, thereby reducing or completely avoiding interference.

The control signaling in each subframe is more problematic as it spans the full cell bandwidth and is not subject to ICIC. LTE Rel-10 offers two ways to handle thi s:

- frequency-domain schemes; and
- time-domain schemes.

Frequency-domain schemes

In frequency-domain schemes, carrier aggregation (CA) is used to separate control signaling for the different cell layers. At least one component carrier in each cell layer is protected from interference from other cell layers by not transmitting control signaling on the component carrier in question. For example, referring to Figure 2, the macro base station transmits control signaling on component carrier f_1 but not on component carrier f_2, and vice versa for the low-power nodes located within the macro cell.

Cross-carrier scheduling is used to schedule data on all the component carriers in each cell layer, subject to the normal ICIC mechanism. Essentially, this creates a frequency reuse for control signaling, while still allowing terminals to dynamically utilize the full bandwidth (and thereby supporting the highest data rates) for the data part.

For example, an operator with 20MHz of spectrum may choose to configure two component carriers of 10MHz each and use carrier aggregation as described above. In addition to the benefits of connecting to the low-power node (dashed area in Figure 2), carrier-aggregation capable terminals will have the same peak data rates as in the case of a single 20MHz carrier. Rel-8/9 can also benefit from seeing a larger pico cell but can only access one component carrier.

Time-domain schemes

In time-domain schemes (non-CA-based) there is one component carrier in each cell layer. Time-domain separation of control signaling in the different cell layers can be used to handle interference. Some subframes in the low-power cell layer are protected from interference where the macro layer has muted control signaling. However, for backward compatibility reasons, cell-specific reference signals still need to be transmitted from the macro cell. By employing time-domain separation, Rel-8/9 terminals in the dashed area in Figure 2 will connect to the macro and not the low-power node and can access the full bandwidth of the carrier.

The discussion above assumes that terminals in both frequency-domain and time-domain schemes are allowed to connect to the low-power node, known as *open access*, and typically the low-power nodes are operator-deployed.

The terms Home-eNB and femto base *station* usually describe low-power base stations deployed by users at more or less random locations (from the operator's perspective). Home-eNBs rely on the users' fixed broadband for backhaul and are often associated with a *closed subscriber group* (CSG), where access is limited to specific users or terminals that are part of the CSG.

The use of CSG results in additional interference scenarios. For example, a terminal located close to, but not admitted to connect to the Home-eNB (as it is not part of the CSG), will be subject to strong interference and may not be able to access the macro cell. The presence of a Home-eNB may cause coverage holes in the operator's macro network. Similarly, reception at the Home-eNB may be severely impacted by uplink transmissions from the terminal connected to the macro cell. Thus, to protect the macro layer from severe interference in the case of Home-eNB with CSG, it is preferable to use separate carriers for the Home-eNB layer, possibly in combination with frequency-domain operation as outlined above.

Relaying

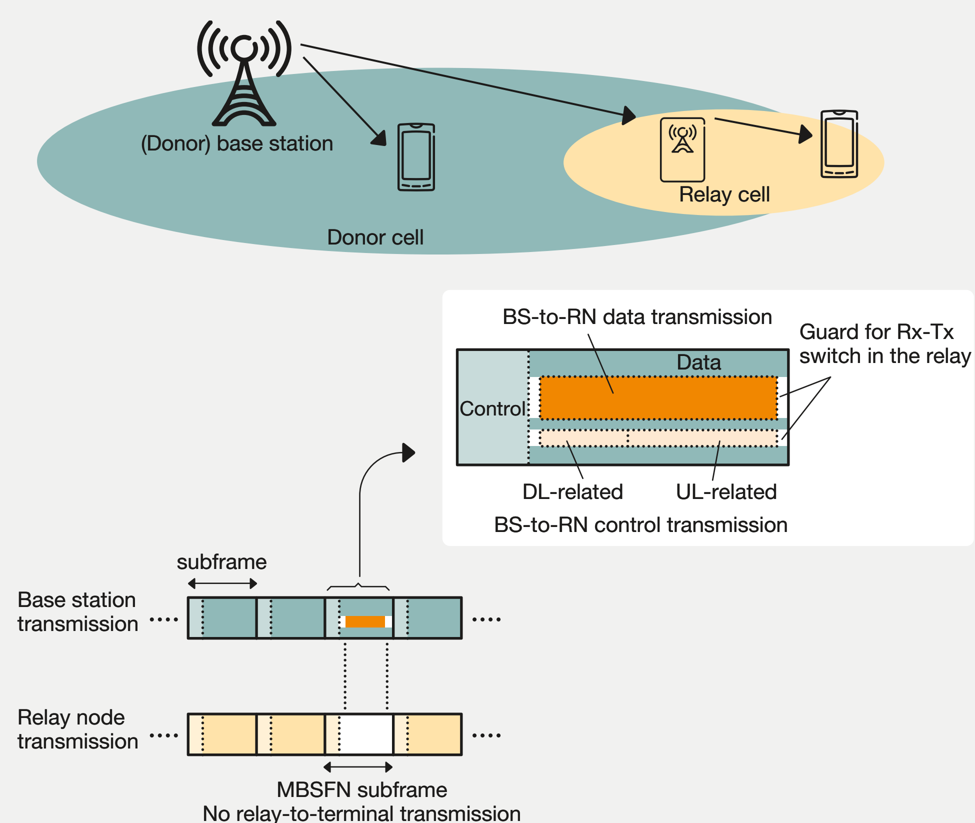
LTE Rel-10 extends LTE radio access technology with support for *relaying functionality* **(Figure 3)**. In case of relaying, the mobile terminal communicates with the network via a relay node that is wirelessly connected to a donor cell using the LTE radio interface technology. Note that the donor cell will typically not only serve the relay node, but also terminals directly connected to the donor cell. The donor-relay link may operate on the same frequency as the relay-terminal link (inband relaying) or on a different frequency (outband relaying).

With the 3GPP relaying solution [3], the relay node will, from a terminal point of view, appear as an ordinary cell. This has the important advantage of simplifying the terminal implementation and making the relay node backward compatible. Essentially, the relay is a (low-power) base station wirelessly connected to the remaining part of the network using the LTE radio access technology.

One of the attractive features provided by a relay is improving coverage in the LTE-based wireless backhaul by simply placing relays at problematic locations in, for example, indoor environments. If the traffic situation demands, the wireless donor-relay link could be replaced, for example, by an optical fiber to serve the relay so that precious radio resources in the donor cell could be used for terminal communication.

As the relay transmitter can cause interference to its own receiver, simultaneous donor-to-relay and relay-to-terminal transmission may not be feasible unless the outgoing and incoming signals are sufficiently isolated. Isolation can be achieved by well separated and well isolated antenna

FIGURE 3 **Relaying.**



structures, or through the use of outband relaying.

Similarly, at the relay it may not be possible to receive transmissions from terminals and transmit them to the donor cell at the same time. To handle interference, Rel-10 creates a gap in the relay-to-terminal transmissions using MBSFN subframes*, as shown in Figure 3.

In an MBSFN subframe, the first one or two OFDM symbols are transmitted as usual carrying cell-specific reference signals and downlink control signaling. The remainder of the MBSFN subframe is not used and therefore can be used for the donor-to-relay communication.

The benefit of using MBSFN subframes compared to blanking transmission in the whole subframe is backward compatibility with Rel-8/9 terminals. Blanking the whole subframe is not compatible with Rel-8/9, as such terminals assume that cell-specific reference signals are present in (part of) each subframe. In addition, MBSFN subframes are supported from Rel-8.

Since the relay needs to transmit cell-specific reference signals in the first part of an MBSFN subframe, it cannot receive the normal control signaling from the donor cell. Therefore, Rel-10 defines a new control channel, transmitted later in the subframe, as shown in Figure 3, to provide control signaling from the donor to the relay.

In the same way as normal control signaling, this control channel type, of which multiple instances can be configured, carries downlink (donor-to-relay) scheduling assignments and uplink (relay-to-donor) scheduling grants. As the assignments refer to data in the same subframe, early decoding of this control information is beneficial. For this reason, downlink assignments are transmitted in the first part of the donor-to-relay transmission, while the latter part is used for less time-critical uplink grants relating to a subsequent subframe.

Performance Results

ITU has defined some requirements for IMT-Advanced technology[2]. Some of the most basic of these requirements, together with the corresponding capabilities of LTE[4], are summarized in Table 1.

The first release of LTE meets all of the advanced requirements except those for bandwidth and uplink peak spectral efficiency. These requirements are addressed in Rel-10 through carrier aggregation and uplink spatial multiplexing, respectively.

3GPP has extensively evaluated the performance of LTE radio access technology in relation to the IMT-Advanced requirements. Examples of LTE system performance, for downlink and uplink, FDD and TDD, and for the different test environments specified by the ITU (indoor hotspot; urban micro; urban macro; and rural macro) are shown in **Figure 4**. LTE Rel-10 fulfills and even surpasses all of the IMT-Advanced requirements (indicated by the dashed lines in Figure 4). Detailed assumptions for the evaluations outlined in Figure 4 can be found in reference [6].

These performance results were achieved without any of the extended features in Rel-10. Thus, LTE generation Rel-8 fulfills the subset of IMT-Advanced requirements on average for cell-edge spectral efficiency.

This, however, does not imply that Rel-10 features, such as extended downlink multi-antenna transmission and relaying functionality, are redundant. Rather, these features take the capabilities of the LTE radio access technology beyond IMT-Advanced. By including more advanced features, such as extended multi-antenna transmission, LTE system performance is enhanced beyond what is illustrated. A wider range of deployment scenarios is also addressed, including those with relays and non-contiguous spectrum allocations.

*MBSFN (Multicast-Broadcast Single Frequency Network) subframes, present already in Rel-8, were originally intended for broadcast support, but have later been seen as a generic tool, for example, to blank parts of a subframe for relaying support.

FIGURE 4 **Performance results for FDD, TDD, downlink and uplink.**

Conclusion

This article has provided an overview of the evolution of LTE, also referred to as LTE-Advanced. By introducing several new features, including carrier aggregation, enhanced multi-antenna support, and relaying, LTE-Advanced significantly boosts the performance and service capabilities of LTE radio access technology. LTE-Advanced has also been approved by ITU as an IMT-Advanced technology, thus confirming the characteristics of LTE as a 4G technology.

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