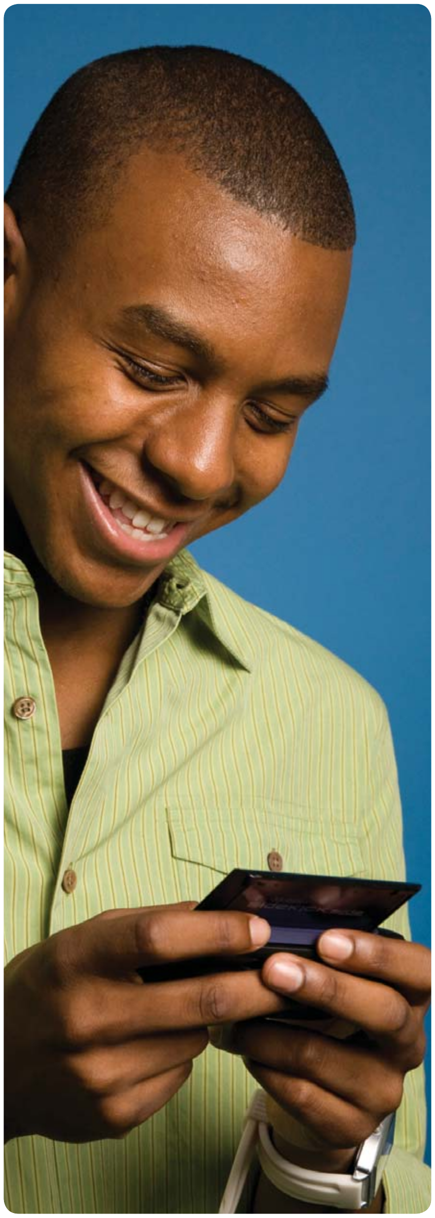
Introducing LTE-Advanced

Application Note



LTE-Advanced (LTE-A) is the project name of the evolved version of LTE that is being developed by 3GPP. LTE-A will meet or exceed the requirements of the International Telecommunication Union (ITU) for the fourth generation (4G) radio communication standard known as IMT-Advanced. LTE-Advanced is being specified initially as part of Release 10 of the 3GPP specifications, with a functional freeze targeted for March 2011. The LTE specifications will continue to be developed in subsequent 3GPP releases.

In October 2009, the 3GPP Partners formally submitted LTE-Advanced to the ITU Radiocommunication sector (ITU-R) as a candidate for 4G IMT-Advanced [1]. Publication by the ITU of the specification for IMT-Advanced is expected by March 2011. As more and more wireless operators announce plans to deploy LTE in their next-generation networks, interest in LTE-Advanced is growing.

This application note covers the following topics:

- Summary of the ITU requirements for 4G
- Summary of 3GPP requirements for LTE-Advanced, including the expected timeline
- Key solution proposals for LTE-Advanced
- Release 10 and beyond: Technologies under consideration
- Anticipated design and test challenges

The application note also introduces Agilent's LTE-Advanced design and test solutions that are ready for use by early adopters. These solutions will be continuously enhanced as the LTE-Advanced specifications are released.

To get the most from this application note, you should have knowledge of the basic concepts of LTE technology. Detailed information is available in Agilent's book *LTE and the Evolution to 4G Wireless: Design and Measurement Challenges* (ISBN 978-988-17935-1-5) www.agilent.com/find/ltebook and in the application note "3GPP Long Term Evolution: System Overview, Product Development, and Test Challenges" (literature number 5989-8139EN), available at www.agilent.com/find/LTE.

Please note that because the final scope and content of the Release 10 specifications are still to be decided, the information covered in this application note is subject to change.

Agilent Technologies

Table of Contents

Overview of LTE and LTE-Advanced

Fourth generation wireless technology has been anticipated for quite some time. To understand the evolutionary changes in 4G and LTE-Advanced, it may be helpful to summarize what came before.

Evolution of wireless standards

Wireless communications have evolved from the so-called second generation (2G) systems of the early 1990s, which first introduced digital cellular technology, through the deployment of third generation (3G) systems with their higher speed data networks to the much-anticipated fourth generation technology being developed today. This evolution is illustrated in Figure 1, which shows that fewer standards are being proposed for 4G than in previous generations, with only two 4G candidates being actively developed today: 3GPP LTE-Advanced and IEEE 802.16m, which is the evolution of the WiMAX standard known as Mobile WiMAX™.

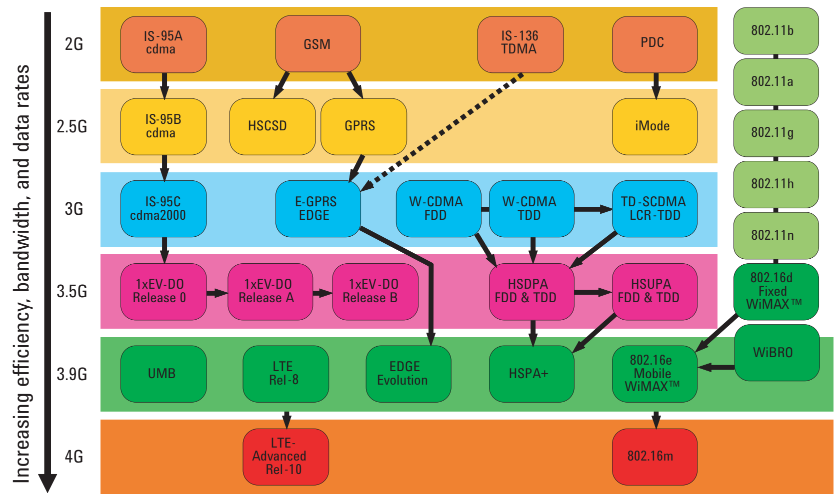


Figure 1. Wireless evolution 1990–2010 and beyond

Early 3G systems, of which there were five, did not immediately meet the ITU 2 Mbps peak data rate targets in practical deployment although they did in theory. However, there have been improvements to the standards since then that have brought deployed systems closer to and now well beyond the original 3G targets.

Table 1 shows the evolution of 3GPP's third generation Universal Mobile Telecommunication System (UMTS), the original wideband CDMA technology, starting from its initial release in 1999/2000. There have been a number of different releases of UMTS, and the addition of High Speed Downlink Packet Access (HSDPA) in Release 5 ushered in the informally named 3.5G. The subsequent addition of the Enhanced Dedicated Channel (E-DCH), better known as High Speed Uplink Packet Access (HSUPA), completed 3.5G. The combination of HSDPA and HSUPA is now referred to as High Speed Packet Access (HSPA). LTE arrived with the publication of the Release 8 specifications in 2008 and LTE-Advanced is being introduced as part of Release 10. The LTE-Advanced radio access network (RAN) functionality is planned to be functionally frozen by December 2010 (excluding the ASN.1 definitions) and the overall Release 10 functional freeze is targeted for March 2011.

Table 1. Evolution of UMTS specifications

Release	Functional Freeze	Main Radio Features of the Release
Rel-99	March 2000	UMTS 3.84 Mcps (W-CDMA FDD & TDD)
Rel-4	March 2001	1.28 Mcps TDD (aka TD-SCDMA)
Rel-5	June 2002	HSDPA
Rel-6	March 2005	HSUPA (E-DCH)
Rel-7	Dec 2007	HSPA+ (64QAM DL, MIMO, 16QAM UL), LTE & SAE feasibility study, EDGE Evolution
Rel-8	Dec 2008	LTE work item – OFDMA air interface, SAE work item, new IP core network, 3G femtocells, dual carrier HSDPA
Rel-9	Dec 2009	Multi-standard radio (MSR), dual cell HSUPA LTE-Advanced feasibility study, SON, LTE femtocells
Rel-10	March 2011	LTE-Advanced (4G) work item, CoMP study, four carrier HSDPA

Summary of LTE features

The Long Term Evolution project was initiated in 2004 [2]. The motivation for LTE included the desire for a reduction in the cost per bit, the addition of lower cost services with better user experience, the flexible use of new and existing frequency bands, a simplified and lower cost network with open interfaces, and a reduction in terminal complexity with an allowance for reasonable power consumption.

These high level goals led to further expectations for LTE, including reduced latency for packets, and spectral efficiency improvements above Release 6 high speed packet access (HSPA) of three to four times in the downlink and two to three times in the uplink. Flexible channel bandwidths—a key feature of LTE—are specified at 1.4, 3, 5, 10, 15, and 20 MHz in both the uplink and the downlink. This allows LTE to be flexibly deployed where other systems exist today, including narrowband systems such as GSM and some systems in the U.S. based on 1.25 MHz.

Speed is probably the feature most associated with LTE. Examples of downlink and uplink peak data rates for a 20 MHz channel bandwidth are shown in Table 2. Downlink figures are shown for single input single output (SISO) and multiple input multiple output (MIMO) antenna configurations at a fixed 64QAM modulation depth, whereas the uplink figures are for SISO but at different modulation depths. These figures represent the physical limitation of the LTE frequency division duplex (FDD) radio access mode in ideal radio conditions with allowance for signaling overheads. Lower rates are specified for specific UE categories, and performance requirements under non-ideal radio conditions have also been developed. Figures for LTE's time division duplex (TDD) radio access mode are comparable, scaled by the variable uplink and downlink ratios.

Table 2. Peak data rates for LTE

Downlink peak data rates (64 QAM)			
Antenna configuration	SISO	2x2 MIMO	4x4 MIMO
Peak data rate Mbps	100	172.8	326.4
Uplink peak data rates (single antenna)			
Modulation	QPSK	16 QAM	64 QAM
Peak data rate Mbps	50	57.6	86.4

Unlike previous systems, LTE is designed from the beginning to use MIMO technology, which results in a more integrated approach to this advanced antenna technology than does the addition of MIMO to legacy system such as HSPA.

Finally, in terms of mobility, LTE is aimed primarily at low mobility applications in the 0 to 15 km/h range, where the highest performance will be seen. The system is capable of working at higher speeds and will be supported with high performance from 15 to 120 km/h and functional support from 120 to 350 km/h. Support for speeds of 350 to 500 km/h is under consideration.

What's new in LTE-Advanced

In the feasibility study for LTE-Advanced, 3GPP determined that LTE-Advanced would meet the ITU-R requirements for 4G. The results of the study are published in 3GPP Technical Report (TR) 36.912. Further, it was determined that 3GPP Release 8 LTE could meet most of the 4G requirements apart from uplink spectral efficiency and the peak data rates. These higher requirements are addressed with the addition of the following LTE-Advanced features:

- Wider bandwidths, enabled by carrier aggregation
- Higher efficiency, enabled by enhanced uplink multiple access and enhanced multiple antenna transmission (advanced MIMO techniques)

Other performance enhancements are under consideration for Release 10 and beyond, even though they are not critical to meeting 4G requirements:

- Coordinated multipoint transmission and reception (CoMP)
- Relaying
- Support for heterogeneous networks
- LTE self-optimizing network (SON) enhancements
- Home enhanced-node-B (HeNB) mobility enhancements
- Fixed wireless customer premises equipment (CPE) RF requirements

These features and their implications for the design and test of LTE-Advanced systems will be discussed in detail later in this application note.

3GPP documents for LTE-Advanced

3GPP publishes all the documents relating to the development of LTE-Advanced. These documents are free to the public and can be downloaded from the 3GPP web site (www.3GPP.org) or at the addresses given below. The versions and dates shown here are current at the time of this writing.

Study Item RP-080599
Outlines the overall goals of LTE-Advanced
ftp://ftp.3gpp.org/tsg_ran/TSG_RAN/TSGR_41/Docs/RP-080599.zip

Requirements TR 36.913 v9.0.0 (2009-12)
Defines requirements based on the ITU requirements for 4G systems
ftp://ftp.3gpp.org/Specs/html-info/36913.htm

Study Phase Technical Report TR 36.912 v9.3.0 (2010-06)
Summarizes the stage 1 development work
ftp://ftp.3gpp.org/Specs/html-info/36912.htm

Study item final status report RP-100080
ftp://ftp.3gpp.org/tsg_ran/TSG_RAN/TSGR_47/Docs/RP-100080.zip

Physical Layer Aspects TR 36.814 v9.0.0 (2010-03)
Summarizes the stage 2 development for the physical layer
ftp://ftp.3gpp.org/Specs/html-info/36814.htm

Study phase Technical Report on E-UTRA UE Radio Transmission and Reception
TR 36.807
Summarizes study of CA, enhanced multiple antenna transmission and CPE
ftp.3gpp.org/Specs/html-info/36807.htm

Stage 3 technical specifications begin to appear in the Release 10 36-series documents dated 2010-09.

LTE-Advanced timeline

Work on Release 8 LTE, including test development, is expected to be finished in 2010. The Global Certification Forum (GCF) released its scheme for test validation in early 2010 and will release a scheme for User Equipment (UE) certification by late 2010, when it expects to see the first major wave of LTE commercial network rollouts [3]. Deployment is expected to continue over the next few years. The deployment timeline for LTE-Advanced will be influenced by the success of LTE in the market.

Figure 2 shows the timeline for the development of IMT-Advanced and LTE-Advanced. At the top of the figure is the timeline of the ITU-R, which is developing the fourth generation requirements, which are described in more detail in the next section. In March 2008, the ITU-R issued an invitation for proposals for a new radio interface technology (RIT), with a cutoff date of October 2009 for submission of candidate RIT proposals. The cutoff date for submitting the technology evaluation report to the ITU was June 2010. In October 2010 the ITU Working Party 5D (WP 5D) decided that the first two RITs to meet the IMT-Advanced requirements were 3GPP's LTE-Advanced and IEEE's WirelessMAN-Advanced, which is also known as 802.16m [4]. WP 5D is scheduled to complete development of radio interface specification recommendations by February 2011.

The bottom of Figure 2 shows the work by 3GPP on LTE-Advanced, which is occurring in parallel with the development of the ITU requirements. With the completion of the documents listed at the bottom of the figure, 3GPP formally submitted LTE-Advanced to the ITU as an IMT-Advanced candidate technology.

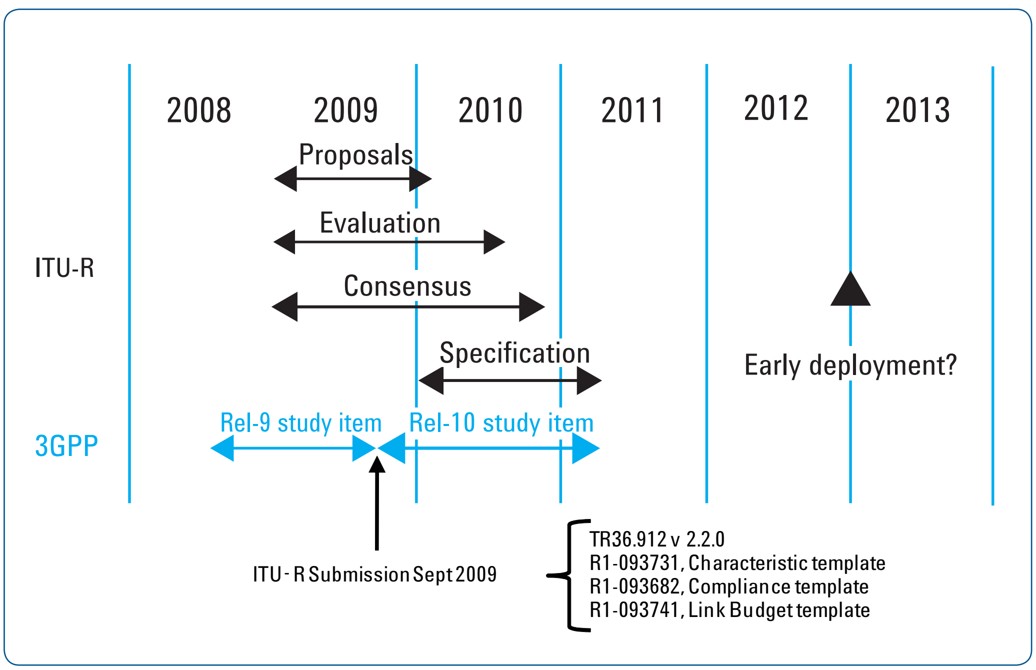


Figure 2. Timelines for IMT-Advanced (4G) and LTE-Advanced development

ITU Requirements for IMT-Advanced (4G)

The third generation of cellular radio technology was defined by the ITU-R through the International Mobile Telecommunications 2000 project (IMT-2000). The requirements for IMT-2000, defined in 1997, were expressed only in terms of peak user data rates:

- 2048 kbps for indoor office
- 384 kbps for outdoor to indoor and pedestrian
- 144 kbps for vehicular
- 9.6 kbps for satellite

Of significance is that there was no requirement defined for spectral efficiency in 3G. The situation is quite different for IMT-Advanced.

The ITU's high level requirements for IMT-Advanced include the following [5]:

- A high degree of common functionality worldwide while retaining the flexibility to support a wide range of local services and applications in a cost-efficient manner
- Compatibility of services within IMT and with fixed networks
- Capability for interworking with other radio systems
- High quality mobile services
- User equipment suitable for worldwide use
- User-friendly applications, services, and equipment
- Worldwide roaming capability
- Enhanced peak data rates to support advanced mobile services and applications (in the downlink, 100 Mbps for high mobility and 1 Gbps for low mobility)

For the most part these are general purpose requirements that any good standard would attempt to achieve. The key requirement that sets 4G apart from previous standards is reflected in the last item, which gives the expectations for peak data rates that reach as high 1 Gbps for low mobility applications and 100 Mbps for high mobility. This is a huge increase from 3G, which specified a peak rate of 2 Mbps for indoor low mobility applications and 144 kbps vehicular. The peak rates targeted for 4G will have fundamental repercussions on system design.

To date, 14 industry groups have registered with the ITU to evaluate whether or not the technology proposals submitted as candidates for 4G meet the requirements.

In addition to the general requirements above there are specific requirements for spectral efficiency summarized later in Table 3.

3GPP Requirements for LTE-Advanced

The work by 3GPP to define a 4G candidate radio interface technology started in Release 9 with the study phase for LTE-Advanced. The requirements for LTE-Advanced are defined in 3GPP Technical Report (TR) 36.913, "Requirements for Further Advancements for E-UTRA (LTE-Advanced) [6]." These requirements are based on the ITU requirements for 4G and on 3GPP operators' own requirements for advancing LTE. Major technical considerations include the following:

- Continual improvement to the LTE radio technology and architecture
- Scenarios and performance requirements for interworking with legacy radio access technologies
- Backward compatibility of LTE-Advanced with LTE. An LTE terminal should be able to work in an LTE-Advanced network and vice versa. Any exceptions will be considered by 3GPP.
- Account taken of recent World Radiocommunication Conference (WRC-07) decisions regarding new IMT spectrum as well as existing frequency bands to ensure that LTE-Advanced geographically accommodates available spectrum for channel allocations above 20 MHz. Also, requirements must recognize those parts of the world in which wideband channels are not available.

3GPP cites the fact that IMT-conformant systems will be candidates for any new spectrum bands identified by WRC-07 as one reason to align LTE-Advanced with IMT-Advanced [7]. In addition, it is significant that the ITU has renamed its IMT-2000 spectrum as "IMT" spectrum with the intention that all spectrum previously identified for IMT-2000 (3G) is also applicable for IMT-Advanced (4G). This is significant because it means there is no such thing as 3G spectrum or 4G spectrum; there is just one pool of IMT spectrum. What then drives deployment of specific technologies in specific bands will depend on local circumstances. It could be argued this ITU decision frees up the industry to make appropriate local decisions but it also has the effect of increasing the likely fragmentation of markets. The frequency band choices for early 2G and 3G systems were far simpler and focused the industry on one or two key bands (900 MHz for GSM and 2.1 GHz for W-CDMA). No comparable focus exists for LTE and LTE-Advanced, with Release 10 having upwards of 30 bands defined from the outset.

System performance requirements

The system performance requirements for LTE-Advanced will in most cases exceed those of IMT-Advanced. The 1 Gbps peak data rate required by the ITU will be achieved in LTE-Advanced using 4x4 MIMO and transmission bandwidths wider than approximately 70 MHz [8]. In terms of spectral efficiency, today's LTE (Release 8) satisfies the 4G requirement for the downlink, but not for the uplink.

Table 3 compares the spectral efficiency targets for LTE, LTE-Advanced, and IMT-Advanced. Note that the peak rates for LTE-Advanced are substantially higher than the 4G requirements, which highlights a desire to drive up peak performance in 4G LTE, although targets for average performance are closer to ITU requirements. It's worth noting that peak targets, because they can be met in ideal circumstances, are often easier to demonstrate than average targets. However, TR 36.913 states that targets for average spectral efficiency and for cell-edge user throughput efficiency should be given higher priority than targets for peak spectral efficiency and other features such as VoIP capacity[5]. Thus the work of LTE-Advanced should be focused on the very real challenges of raising average and cell-edge performance.

Table 3. Performance targets for LTE, Advanced-LTE, and IMT-Advanced

Item	Subcategory	LTE (3.9G) target [9]	LTE-Advanced (4G) target [10]	IMT-Advanced (4G) target [11]
Peak spectral efficiency (b/s/Hz)	Downlink	16.3 (4x4 MIMO)	30 (up to 8x8 MIMO)	15 (4x4 MIMO)
	Uplink	4.32 (64 QAM SISO)	15 (up to 4x4 MIMO)	6.75 (2x4 MIMO)
Downlink cell spectral efficiency (b/s/Hz), 3 km/h, 500 m ISD	2x2 MIMO	1.69	2.4	
	4.2 MIMO	1.87	2.6	2.6
	4x4 MIMO	2.67	3.7	
Downlink cell-edge user spectral efficiency (b/s/Hz) 5 percentile, 10 users, 500 m ISD	2x2 MIMO	0.05	0.07	
	4x2 MIMO	0.06	0.09	0.075
	4x4 MIMO	0.08	0.12	

**Note: ISD = Inter-site distance*

Spectrum flexibility

In addition to the bands currently defined for LTE Release 8, TR 36.913 identifies the following new bands:

- 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

Some of these bands are now formally included in the 3GPP Release 9 and Release 10 specifications. Note that frequency bands are considered release-independent features, which means that it is acceptable to deploy an earlier release product in a band not defined until a later release.

LTE-Advanced is designed to operate in spectrum allocations of different sizes, including allocations wider than the 20 MHz in Release 8, in order to achieve higher performance and target data rates. Although it is desirable to have bandwidths greater than 20 MHz deployed in adjacent spectrum, the limited availability of spectrum means that aggregation from different bands is necessary to meet the higher bandwidth requirements. This option has been allowed for in the IMT-Advanced specifications.

LTE-Advanced and Other Release 10 Solution Proposals

Proposed solutions for achieving LTE-Advanced performance targets for the radio interface are defined in 3GPP TR 36.814, "Further Advancements for E-UTRA Physical Layer Aspects." [12] A comprehensive summary of the overall LTE-Advanced proposals including radio, network, and system performance can be found in the 3GPP submissions to the first IMT-Advanced evaluation workshop. [13] The remainder of this application note will focus on the radio interface of LTE-Advanced and other Release 10 features.

The following are current solution proposals for the LTE-Advanced radio interface.

LTE-Advanced key technologies

- Carrier aggregation
- Enhanced uplink multiple access
- Enhanced multiple antenna transmission

Within Release 10 there is other ongoing work that is complementary to LTE-Advanced but not considered essential for meeting the ITU requirements.

Release 10 and beyond: Technologies under consideration

- Coordinated multipoint transmission and reception (CoMP)
- Relaying
- Support for heterogeneous networks
- LTE self-optimizing networks (SON)
- HNB and HeNB mobility enhancements
- CPE RF requirements

We'll examine each of these categories from the physical layer perspective, along with some of the associated design and test challenges.

Prior to the elaboration of the Release 10 UE radio specifications in 36.101, Technical Report (TR) 36.807 [14] is being drafted. This will cover the following Release 10 features:

- Carrier Aggregation (CA)
- Enhanced DL multiple antenna (DLMA) transmission
- UL multiple antenna (ULMA) transmission
- Fixed wireless CPE RF requirements

Like most technical reports, this document contains useful background information on how the requirements were developed which will not necessarily be evident in the final technical specifications.

Release 10 new UE categories

The existing UE categories 1-5 for Release 8 and Release 9 are shown in Table 4. In order to accommodate LTE-Advanced capabilities, three new UE categories 6-8 have been defined. [15]

Table 4. Release 10 UE categories

UE category	Max. data rate (DL/UL) (Mbps)	Downlink				Uplink		
		Max. # DL-SCH TB bits/ TTI	Max. # DL-SCH bits/TB/ TTI	Total soft channel bits	Max. #. spatial layers	Max.# UL-SCH TB bits/TTI	Max. # UL-SCH bits/TB/ TTI	Support for 64 QAM
Category 1	10/5	10296	10296	250368	1	5160	5160	No
Category 2	50/25	51024	51024	1237248	2	25456	25456	No
Category 3	100/50	102048	75376	1237248	2	51024	51024	No
Category 4	150/50	150752	75376	1827072	2	51024	51024	No
Category 5	300/75	299552	149776	3667200	4	75376	75376	Yes
Category 6	300/50	[299552]	[TBD]	[3667200]	*	[51024]	[TBD]	No
Category 7	300/150	[299552]	[TBD]	[TBD]	*	[150752/102048 (Up to RAN4)]	[TBD]	Yes/No (Up to RAN4)
Category 8	1200/600	[1200000]	[TBD]	[TBD]	*	[600000]	[TBD]	Yes

**See Tables 5 and 6*

Note that category 8 exceeds the requirements of IMT-Advanced by a considerable margin.

Given the many possible combinations of layers and carrier aggregation, many configurations could be used to meet the data rates in Table 4. Tables 5 and 6 define the most probable cases for which performance requirements will be developed.

Table 5. Downlink configurations

UE category	DL CA capability #CCs/BW(MHz) *[provisional]*	DL layers max # layers *[provisional]*
Category 6	1/20 MHz	4
	2/10+10 MHz	4
	2/20+20 MHz	2
	2/10+20 MHz	4 (10 MHz) 2 (20 MHz)
Category 7	120 MHz	4
	1/20+10 MHz	4
	2/20+20 MHz	2
	2/10+20 MHz	4 (10 MHz) 2 (20 MHz)
Category 8	*[2/20+20 MHz]*	*[8]*

Table 6. Uplink configurations

UE category	DL CA capability #CCs/BW(MHz) *[provisional]*	DL layers max # layers *[provisional]*
Category 6	1/20 MHZ	1
	2/10+10 MHz	1
	1/10 MHz	2
Category 7	2/20+20 MHZ	1
	1/20 MHz	2
	2/10+20 MHz	2 (10 MHz) 1 (20 MHz)
Category 8	*[2/20+20 MHz]*	*[4]*

LTE-Advanced key technologies

Carrier aggregation

Achieving the 4G target downlink peak data rate of 1 Gbps will require wider channel bandwidths than are currently specified in LTE Release 8. At the moment, LTE supports channel bandwidths up to 20 MHz, and it is unlikely that spectral efficiency can be improved much beyond current LTE performance targets. Therefore the only way to achieve significantly higher data rates is to increase the channel bandwidth. IMT-Advanced sets the upper limit at 100 MHz, with 40 MHz the expectation for minimum performance.

Because most spectrum is occupied and 100 MHz of contiguous spectrum is not available to most operators, the ITU has allowed the creation of wider bandwidths through the aggregation of contiguous and non-contiguous component carriers. Thus spectrum from one band can be added to spectrum from another band in a UE that supports multiple transceivers. Figure 3 shows an example of contiguous aggregation in which two 20 MHz channels are located side by side. In this case the aggregated bandwidth covers the 40 MHz minimum requirement and could be supported with a single transceiver. However, if the channels in this example were non-contiguous—that is, not adjacent, or located in different frequency bands—then multiple transceivers in the UE would be required.

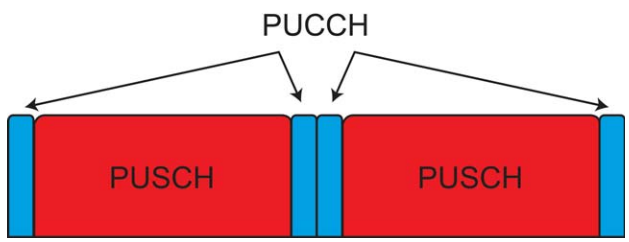


Figure 3. Contiguous aggregation of two uplink component carriers

The term component carrier used in this context refers to any of the bandwidths defined in Release 8/9 LTE. To meet ITU 4G requirements, LTE-Advanced will support three component carrier aggregation scenarios: intra-band contiguous, intra-band non-contiguous, and inter-band non-contiguous aggregation. The spacing between center frequencies of contiguously aggregated component carriers will be a multiple of 300 kHz to be compatible with the 100 kHz frequency raster of Release 8/9 and at the same time preserve orthogonality of the subcarriers, which have 15 kHz spacing. Depending on the aggregation scenario, the *n* x 300 kHz spacing can be facilitated by inserting a low number of unused subcarriers between contiguous component carriers. In the case of contiguous aggregation, more use of the gap between component carriers could be made, but this would require defining new, slightly wider component carriers.

An LTE-Advanced UE with capabilities for receive and/or transmit carrier aggregation will be able to simultaneously receive and/or transmit on multiple component carriers. A Release 8 or 9 UE, however, can receive and transmit on a single component carrier only. Component carriers must be compatible with LTE Release 8 and 9.

In Release 10, the maximum size of a single component carrier is limited to 110 resource blocks, although for reasons of simplicity and backwards compatibility it is unlikely that anything beyond the current 100 RB will be specified. Up to 5 component carriers may be aggregated. An LTE-Advanced UE cannot be configured with more uplink component carriers than downlink component carriers, and in typical TDD deployments the number of uplink and downlink component carriers, as well as the bandwidth of each, must be the same.

For mapping at the physical layer (PHY) to medium access control (MAC) layer interface, there will be one transport block (in the absence of spatial multiplexing) and one hybrid-ARQ entity for each scheduled component carrier. (Hybrid ARQ is the control mechanism for retransmission.) Each transport block will be mapped to a single component carrier only. A UE may be scheduled over multiple component carriers simultaneously. The details of how the control signaling will be handled across the multiple carriers are still being developed.

Aggregation techniques are not new to 4G; aggregation is also used in HSPA and 1xEV-DO Release B. However, the 4G proposal to extend aggregation to 100 MHz in multiple bands raises considerable technical challenges owing to the cost and complexity that will be added to the UE. Moreover, operators will have to deal with the challenge of deciding what bands to pick for aggregation and it may be some time before consensus is reached allowing sufficient scale to drive the vendor community. 3GPP initially identified 12 likely deployment scenarios for study with the intention of identifying requirements for spurious emissions, maximum power, and other factors associated with combining different radio frequencies in a single device. However, because of the number of the scenarios and limited time, the study for Release 10 LTE-Advanced was initially limited to two scenarios, one intra-band TDD example and one inter-band FDD example. In June 2010 a third scenario was added for bands 3 and 7, as shown in Table 7. This scenario is an important combination for Europe, where re-farming of the underused 1800 MHz band currently allocated to GSM is a significant possibility.

Table 7. 3GPP Release 10 carrier aggregation (CA) scenarios for study [16]

Band	E-UTRA operating Band	Uplink (UL) band				Downlink (DL) band				Duplex mode
		UE transmit/BS receive			Channel BW MHz	UE receive/BS transmit			Channel BW MHz	
		F_{UL_low} (MHz) – F_{UL_high} (MHz)				F_{UL_low} (MHz) – F_{UL_high} (MHz)				
CA_40	40	2300	–	2400	[TBD]	1	–	2400	5160	TDD
CA_1-5	1	1920	–	1980	[TBD]	2	–	2170	25456	FDD
	5	824	–	849	[TBD]	2	–	894	51024	
CA_3-7	3	1710	–	1788	20	2	–	1880	51024	FDD
	7	2500	–	2570	20	4	–	2690	75376	

The physical layer definition for CA is considered 80% complete and although the CA concept is simple, the details of the physical layer changes to support the signaling are complex and involve changes to the PCFICH, PHICH, PDCCH, PUCCH, UL power control, PUSCH resource allocation, and the UCI on the PUSCH. The radio performance aspects are only at 30% completion. This is significant, as Table 7 just begins to describe the possible scope of CA. To get some idea of the number of combinations requested by operators, refer to Annex A of TR 36.807. Every combination introduced into the specifications has to be assessed for aspects such as required guard bands, spurious emissions, power back off, and so forth.

One of the new challenges that CA introduces to the radio specifications is the concept of variable TX/RX frequency separation. This attribute impacts specifications for reference sensitivity and receiver blocking, among others. In Release 8 and Release 9, the TX and RX separation for each of the 19 defined FDD bands is fixed. The introduction of CA changes that, since asymmetric uplink and downlink allocations will be commonplace. The asymmetry is driven by three scenarios; different numbers of CCs in the uplink and downlink, different bandwidths of CC in the uplink and downlink, and finally a combination of different bandwidths and numbers of CCs. How to limit the allowed allocations in order to minimize the number of test scenarios is still under study.

Enhanced uplink multiple access

Today's LTE uplink is based on SC-FDMA, a powerful technology that combines many of the flexible aspects of OFDM with the low peak to average power ratio (PAPR) of a single carrier system. However, SC-FDMA requires carrier allocation across a contiguous block of spectrum and this prevents some of the scheduling flexibility inherent in pure OFDM.

LTE-Advanced enhances the uplink multiple access scheme by adopting clustered SC-FDMA, also known as discrete Fourier transform spread OFDM (DFT-S-OFDM). This scheme is similar to SC-FDMA but has the advantage that it allows non-contiguous (clustered) groups of subcarriers to be allocated for transmission by a single UE, thus enabling uplink frequency-selective scheduling and better link performance. Clustered SC-FDMA was chosen in preference to pure OFDM to avoid a significant increase in PAPR. It will help satisfy the requirement for increased uplink spectral efficiency while maintaining backward-compatibility with LTE.

Figure 4 shows a block diagram for the enhanced uplink multiple access (clustered SC-FDMA) process. There is only one transport block and one hybrid ARQ entity per scheduled component carrier. Each transport block is mapped to a single component carrier, and a UE may be scheduled over multiple component carriers simultaneously using carrier aggregation, as described in the previous section.

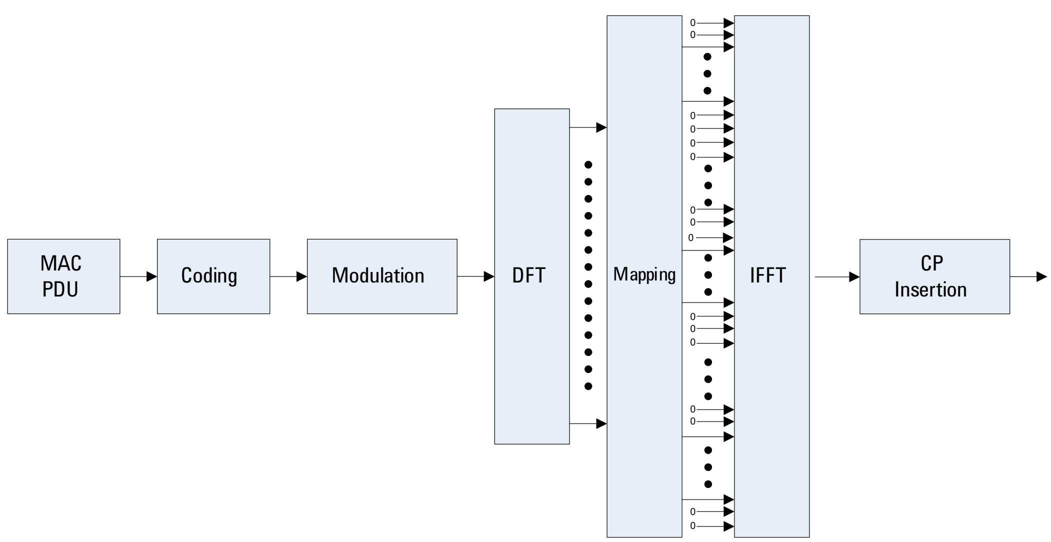


Figure 4. Enhanced uplink multiple access block diagram

Examples of different Release 8 and Release 10 uplink configurations are given in Figure 5. The key point is that all Release 8 configurations are single carrier, which means that the PAPR is no greater than the underlying QPSK or 16QAM modulation format, whereas in Release 10 it is possible to transmit more than one carrier, which makes the PAPR higher than the Release 8 cases. Note that the multiple carriers referred to here as part of clustered SC-FDMA and simultaneous PUCCH/PUSCH are contained within one component carrier and should not be confused with the multiple component carriers of CA.

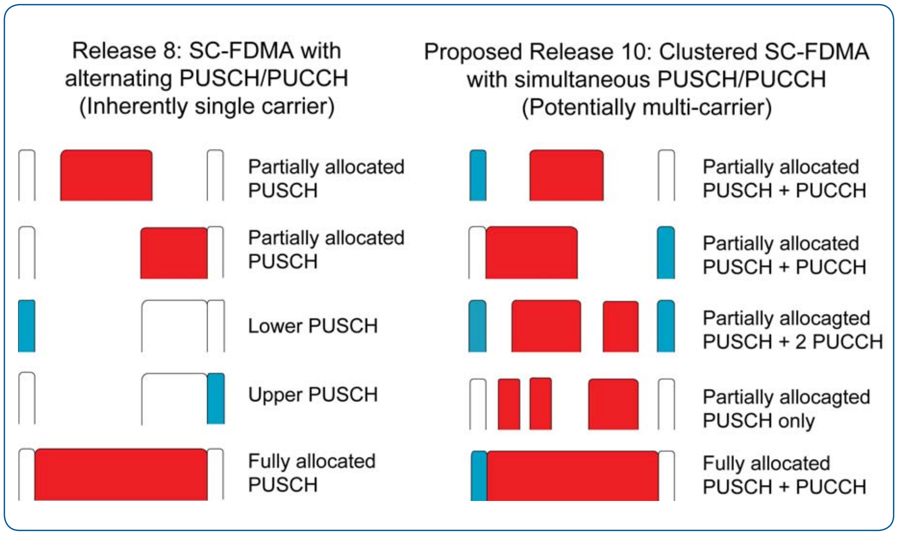


Figure 5. Comparison of Release 8 and proposed Release 10 uplink configurations

The initial specifications are likely to limit the number of SC-FDMA clusters to two, which will provide some improved spectral efficiency over single cluster when transmitting through a frequency-selective channel with more than one distinct peak.

Enhanced multiple antenna transmission

Figure 6 shows the Release-8 LTE limits for antenna ports and spatial multiplexing layers. The downlink supports a maximum of four spatial layers of transmission (4x4, assuming four UE receivers) and the uplink a maximum of one per UE (1x2, assuming an eNB diversity receiver). In Release 8, multiple antenna transmission is not supported in order to simplify the baseline UE, although multiple user spatial multiplexing (MU-MIMO) is supported. In the case of MU-MIMO, two UEs transmit on the same frequency and time, and the eNB has to differentiate between them based on their spatial properties. With this multi-user approach to spatial multiplexing, gains in uplink capacity are available but single user peak data rates are not improved.

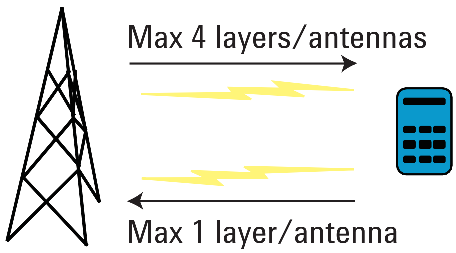


Figure 6. Release 8 LTE maximum number of antenna ports and spatial layers

To improve single user peak data rates and to meet the ITU-R requirement for spectrum efficiency, LTE-Advanced specifies up to eight layers in the downlink which, with the requisite eight receivers in the UE, allows the possibility in the downlink of 8x8 spatial multiplexing. The UE will be specified to support up to four transmitters allowing the possibility of up to 4x4 transmission in the uplink when combined with four eNB receivers. See Figure 7.

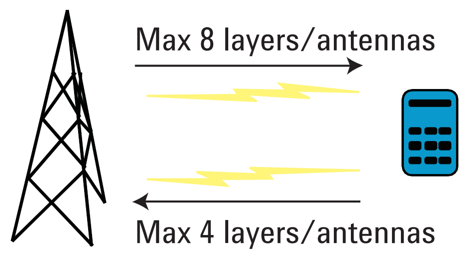


Figure 7. LTE-Advanced maximum number of antenna ports and spatial layers

The work to define the enhanced downlink is about 80% complete. There will be changes to the UE-specific demodulation reference signal (DMRS) patterns to support up to eight antennas. Channel state information reference signals (CSI-RS) and associated modifications to UE feedback in the CSI codebook design will be introduced. There also will be equivalent changes for downlink control signaling.

The specification for DMRS for Ranks 1 to 4 is given in Figure 8. DMRS support for Ranks 5 to 8 is not defined for Release 10 but is not precluded in future releases. Release 10 emphasizes dual-layer spatial multiplexing augmented by four-antenna beamsteering rather than a pure 8-layer spatial multiplexing approach, which would offer higher peak rates but require eight receive antennas in the UE.

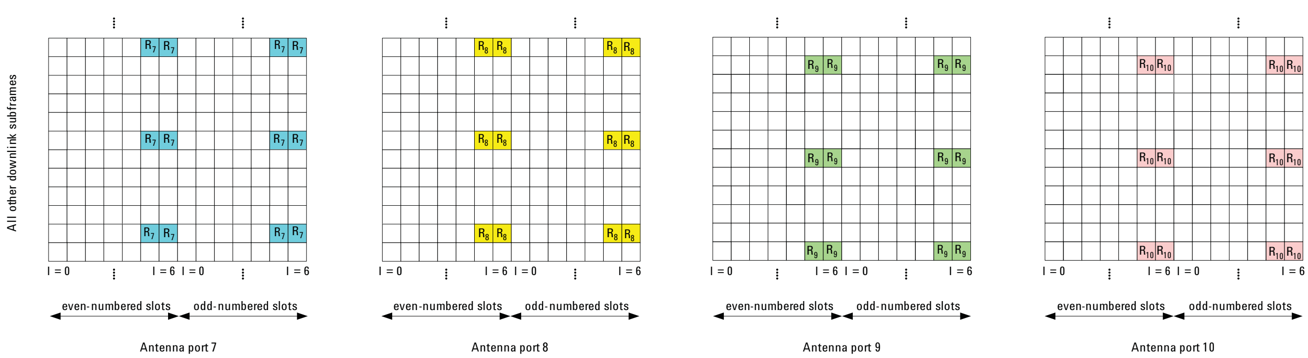


Figure 8. Mapping of UE-specific reference signals; antenna ports 7, 8, 9, and 10 (normal cycle prefix) [17]

The CSI-RS are introduced in the downlink to enable UE-specific weights to be applied to the RS for UE channel measurement purposes according to the CSI feedback. In this way the behavior of the UE-specific RS will track that of the precoded data (PDSCH), which is already optimized for each UE. The design of the CSI-RS offers other advantages over the legacy CRS in that higher reuse factors are available, which makes the introduction of inter-cell interference cancellation (ICIC) more practical. The proposed mappings of the CSI-RS for two, four, and eight antenna ports is given in Figure 9.

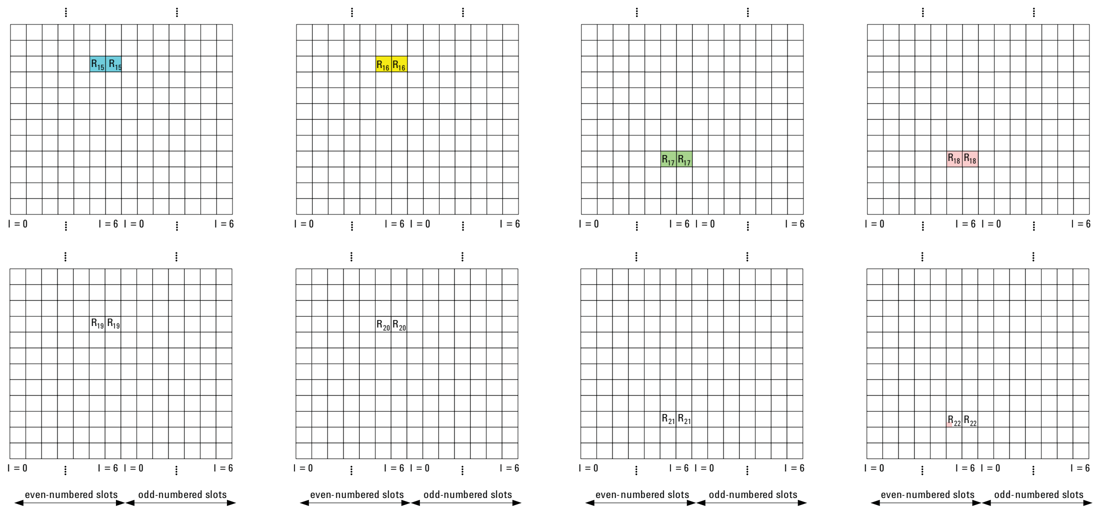


Figure 9. Mapping of CSI reference signals (CSI configuration 0, normal cyclic prefix) [18]

Figure 10 illustrates the resource block (RB) allocation for a 10 MHz FDD signal transmitted over an EPA channel as seen at the antenna of a single input UE. This particular signaling configuration was created using Agilent SystemVue along with a “beta” version of its LTE-Advanced Release 10 library.

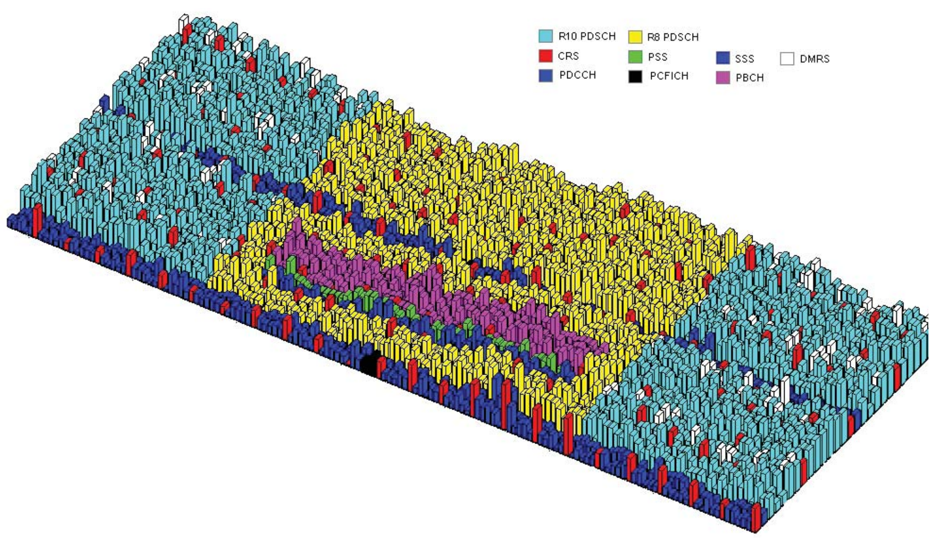


Figure 10. Example of resource block allocation in LTE-Advanced

The allocation shown in Figure10 is extracted from the center 12 RBs in the first two subframes of a 10 MHz FDD downlink signal. Normal cyclic prefix is employed. The first two symbols of each subframe are reserved for the PDCCH. The center of the channel has been used for Release 8 PDSCH and the outer RBs for Release 10 PDSCH. Included in the allocation are cell-specific RS along with Release 10 DMRS.

The principles for a new codebook for the 8Tx case have been agreed to, but for the 2Tx and 4Tx cases, the Release 8 codebook will be reused as it is considered good enough. However, several proposals are being considered to improve CQI/PMI/RI accuracy for both MU-MIMO and SU-MIMO:

- Aperiodic PUSCH CQI mode 3-2 (sub-band CQI + sub-band PMI)
- Extension of Release 8 periodic PUCCH CQI mode 2-1 with sub-band PMI
- Potential enhancement on CQI for MU
- Potential enhancement on interference measurement for CQI
- UE procedure to derive PMI targeting for both MU-MIMO and SU-MIMO

Extensions of some of the Release 8 aperiodic PUSCH CQI feedback modes (1-2, 2-2, and 3-1) is proposed along with extensions of the periodic PUCCH modes 1-1 and 2-1.

Various modifications to the downlink control signaling have been agreed to including the following:

- Support of 2 orthogonal DMRS ports and 2 scrambling sequences for MU-MIMO operation
- No additional signaling to be added for the MU-MIMO case in which one RB is scheduled to more than one UE
- Additions to support the new 8Tx SU-MIMO mode dynamic switching between SU-MIMO and MU-MIMO

Equivalent work is ongoing to define multiple antenna transmission for the uplink. Note that in Release 8 and Release 9, only single antenna uplink transmission was defined, so the work in release 10 is not an enhancement as is the case for multiple antenna downlink transmission, which was defined for four antennas in Release 8 and enhanced to 8 antennas in Release 10. A major issue is how uplink control information (UCI) will be multiplexed between two or more PUSCH. This is also an issue for carrier aggregation. Essential agreements have been reached on resource sizes for HARQ, RI, CQI, and PMI. Agreement has been reached on mapping of the PHICH on the downlink for uplink SU-MIMO, and on the cyclic shift and orthogonal cover code (OCC) definitions for the uplink DMRS. Enhancements to the sounding reference symbols (SRS) have been proposed.

The physical layer definition for multiple antenna transmission is well advanced, although the radio performance aspects for the UE and eNB are still in the early stages of discussion with completion not expected until June 2011.

Release 10 and beyond: Technologies under consideration

Coordinated multipoint transmission and reception

Coordinated multipoint (CoMP) is an advanced variant of MIMO being studied as a means of improving performance for high data rates, cell-edge throughput, and system throughput in high load and low load scenarios.

Figure 11 compares traditional MIMO downlink spatial multiplexing with coordinated multipoint. The most obvious different between the two systems is that with coordinated multipoint, the transmitters do not have to be physically co-located, although they are linked by some type of high speed data connection and can share payload data.

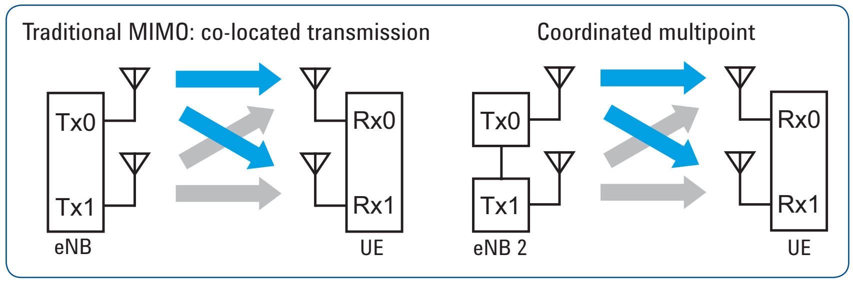


Figure 11. Comparison of traditional downlink MIMO and coordinated multipoint

In the downlink, coordinated multipoint enables coordinated scheduling and beamforming from two or more physically separated locations. These features do not make full use of CoMP's potential, because the data required to transmit to the mobile needs to be present at only one of the serving cells. However, if coherent combining, also known as cooperative or network MIMO, is used, then more advanced transmission is possible.

The CoMP approach to MIMO requires high speed, symbol-level data communication between all the transmitting entities, as indicated on the right hand side of Figure 11 by a line between eNB1 and eNB2. Most likely the physical link carrying the LTE X2 interface, a mesh-based interface between the base stations, will be used for sharing the baseband data.

The coherent combining used in CoMP is somewhat like soft combining or soft handover, a technique that is widely known in CDMA systems in which the same signal is transmitted from different cells. With coherent combining, however, the data streams that are being transmitted from the base stations are not the same. These different data streams are precoded in such a way as to maximize the probability that the UE can decode the different data streams. In the uplink, the use of coordination between the base stations is less advanced, simply because when two or more UEs are transmitting from different places, there is no realistic mechanism for sharing the data between UEs for the purposes of precoding. Thus the uplink is restricted to using the simpler technique of coordinated scheduling. On the other hand, there is considerable opportunity at the eNB receivers to share the received data prior to demodulation to enable more advanced demodulation to be performed. The downside is the consequence that for a 10 MHz signal, the backhaul could be as much as 5 Gbps of low latency connections between the participating eNBs.

Simulations of coordinated multipoint have shown that when the system is not fully loaded, the CoMP process can provide substantial performance gains. However, as the load on the system increases, these gains begin to disappear. 3GPP's recent simulation data showed initial performance improvement to be in the 5% to 15% range. This was not considered sufficient to keep coordinated multipoint as a proposal in Release 10, given the timeline for finalizing the specification. Also, recent results from the EASY-C testbed showed limited performance gains in lightly loaded networks with minimal or no interference. [19] Coordinated multipoint will be studied further for 3GPP Release 11. It remains unclear what eNB testing of CoMP might entail as it is very much a system-level performance gain and is difficult to emulate.

Relaying

Another method of improving coverage in difficult conditions is the use of relaying. The main use cases for relays are to improve urban or indoor throughput, to add dead zone coverage, or to extend coverage in rural areas.

The concept of relaying is not new but the level of sophistication continues to grow. Figure 12 shows a typical scenario. A relay node (RN) is connected wirelessly to the radio access network via a donor cell. In the proposals for Release 10, the RN will connect to the donor cell's eNB (DeNB) in one of two ways:

- In-band (in-channel), in which case the DeNB-to-RN link shares the same carrier frequency with RN-to-UE links.
- Out-band, in which case the DeNB-to-RN link does not operate in the same carrier frequency as RN-to-UE links.

The most basic and legacy relay method is the use of a radio repeater, which receives, amplifies and then retransmits the downlink and uplink signals to overcome areas of poor coverage. In the figure, the repeater could be located at the cell edge or in some other area of poor coverage. Radio repeaters are relatively simple devices operating purely at the RF level. Typically they receive and retransmit an entire frequency band, so they must be sited carefully. In general, repeaters can improve coverage but do not substantially increase capacity.

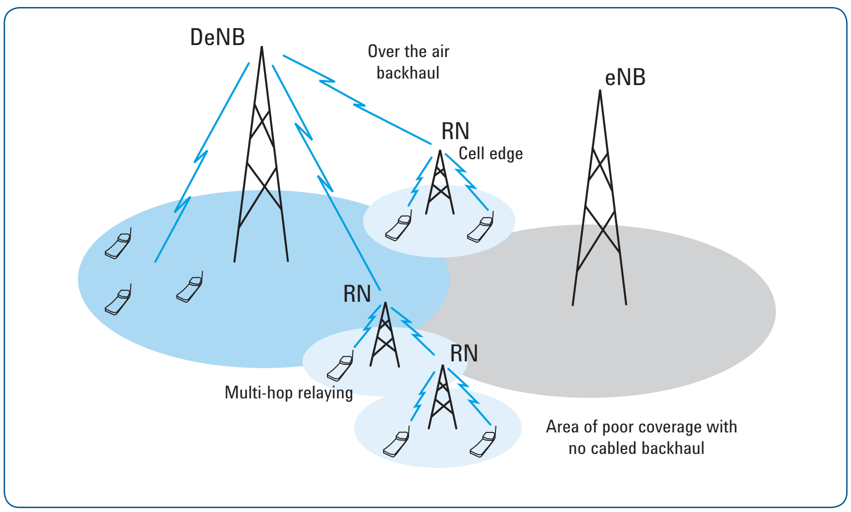


Figure 12. In-channel relay and backhaul

More advanced relays at layer 2 can decode transmissions before retransmitting them. Traffic can then be forwarded selectively to and from the UE local to the RN, thus minimizing the interference created by legacy relays that forward all traffic. Depending on the level at which the protocol stack is terminated in the RN, such types of relay may require the development of relay-specific standards. This can be largely avoided by extending the protocol stack of the RN up to Layer 3 to create a wireless router that operates in the same way that a normal eNB operates, using standard air interface protocols and performing its own resource allocation and scheduling.

The concept of the relay station can be applied in low density deployments where a lack of suitable backhaul would otherwise preclude use of a cellular network. The use of in-band or in-channel backhaul can be optimized using narrow, point-to-point connections to avoid creating unnecessary interference in the rest of the network. Multi-hop relaying is also possible, as Figure 12 shows. In this case a signal is sent from the DeNB to the first RN and then on to the next RN and finally down to the UE. The uplink signal coming back from the UE gets transmitted up through the RNs and back to the DeNB. This technique is possible to do in-channel in an OFDMA system because the channel can be split into UE and backhaul traffic. The link budget between the DeNB and the RN can be engineered to be good enough to allow the use of some of the subframes for backhaul of the relay traffic. These subframes are the ones which otherwise could have been allocated for use with multimedia broadcast in a single frequency network (MBSFN).

In Release 10 progress is being made on the RAN aspects of relaying but it is likely that the network security aspects will be delayed until Release 11. This delay may not affect RAN standardization but may impact deployment.

Support for heterogeneous networks

Release 10 intends to address the support needs of heterogeneous networks that combine low power nodes (such as picocells, femtocells, repeaters, and RNs) within a macrocell. Deployment scenarios under evaluation are detailed in TR 36.814 Annex A. [20]

As the network becomes more complex, the subject of radio resource management is growing in importance. Work is ongoing to develop more advanced methods of radio resource management including new self-optimizing network (SON) features. The Release 10 specifications also continue to develop the use of femtocells and home base stations (HeNBs) introduced in Release 9 as a means of improving network efficiencies and reducing infrastructure costs.

LTE self optimizing network enhancements

Today's cellular systems are very much centrally planned, and the addition of new nodes to the network involves expensive and time-consuming work, site visits for optimization, and other deployment challenges. Some limited SON capability was introduced in Release 8 and is being further elaborated in Release 9 and Release 10.

The intent of SON is to substantially reduce the effort required to introduce new nodes and manage the network. There are implications for radio planning as well as for the operations and maintenance (O&M) interface to the base station.

The main aspects of SON can be summarized as follows:

- Self configuration–The one-time process of automating a specific event, such as the introduction of a new femtocell, by making use of the O&M interface and the network management module
- Self optimization–The continuous process of using environmental data, such as UE and base station measurements, to optimize the current network settings within the constraints set by the configuration process
- Self healing–The process of recovering from an exceptional event caused by unusual circumstances, such as dramatically changing interference conditions or the detection of a ping pong situation in which a UE continuously switches between macro and femto cells.

HeNB mobility enhancements

Another category of network enhancement that will figure prominently in Release 10 is the femtocell or home eNode B (HeNB).

3GPP work on femtocell inclusion in UMTS was ongoing during Release 8 and was extended in Release 9 to LTE with the HeNB. In Release 9 only inbound mobility (macro to HeNB) was fully specified. Further enhancements to enable HeNB to HeNB mobility will be added in Release 10. Currently three different proposals for enabling HeNB to HeNB mobility are being studied and a decision is expected in Dec 2010. This capability is very important for enterprise deployments. Although the femtocell concept is not unique to LTE or LTE-Advanced, an opportunity exists for LTE to incorporate this technology from the start rather than retrospectively designing it into legacy systems such as UMTS and GSM. Figure 13 shows the topology of a femtocell deployment.

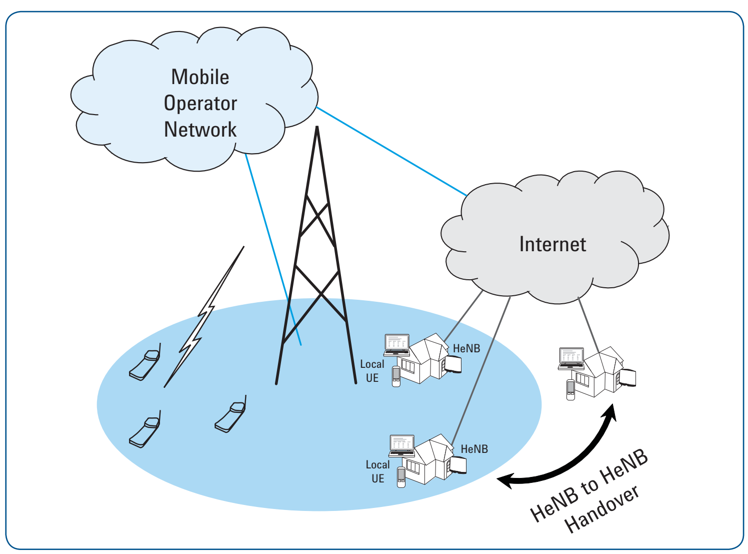


Figure 13. Femtocell deployment in a heterogeneous

From a radio deployment perspective the femtocell operates over a small area within a larger cell. The radio channel could be a channel shared with a larger cell (known as co-channel deployment) or it could be a dedicated channel. The femtocell concept is fundamentally different from relaying since the femtocell connection back into the core network is provided locally by an existing DSL or cable internet connection rather than over the air back to the macrocell. Most femtocell deployments will be indoors, which helps provide isolation between the femtocell and macrocell. Also depicted in Figure 13 is a femtocell outside the macrocell coverage area. This shows how femtocells might be used to provide local cellular coverage in rural areas where DSL service exists but not that of the preferred operator.

Although the term "femtocell" suggests that the major difference from existing systems is one of coverage area, the defining attributes of femtocells are far more numerous than coverage area alone. They include such considerations as infrastructure cost and financing; method of backhaul; network planning, deployment, quality of service, and control; mobility and data throughput performance.

The two main deployment scenarios for femtocells are in the following locations:

- In rural areas with poor or no (indoor) coverage, probably using co-channel deployment
- In dense areas to provide high data rates and capacity

In both cases operators must decide whether the femtocell will be deployed for closed subscriber group (CSG) UE or for open access. This and other practical considerations such as pricing can be considered commercial issues, although in the co-channel CSG case, the probability that areas of dense femtocell deployment will block macrocells becomes an issue.

The potential gains from femtocells are substantial, but they present many challenges. Solutions are needed for many of the following, some of which are being addressed in Release 10:

- Cognitive methods to reduce interference to the macro network
- Radio resource management requirements
- Methods of addressing security concerns associated with users building their own cellular networks
- Verification of geographic location and roaming aspects
- Business models for open- versus closed-access operation
- Support of more than one network per femtocell
- Ownership of the backhaul and the issue of net neutrality
- Optimized and balanced interworking between macrocells and femtocells to minimize unnecessary handovers
- Methods of resolving bottlenecks on fixed broadband backhaul connection, especially on the uplink for services requiring symmetric bandwidths, prioritization, and congestion management
- QoS control for real-time services (such as voice) and applications requiring guaranteed bit rates
- Access control providing closed subscriber group local and roaming access
- Capability for self-configuration, self-organization, self-optimization, and self-healing (including fault management and failure recovery)
- Security, backhaul protection, device and user authentication

In spite of these issues, studies have shown that increases in average data rates and capacity of some 100x are possible with femtocells over what can be achieved from the macro network. On the other hand, femtocells do not provide the mobility of macrocellular systems, and differences exist in the use models of these systems, as shown in Table 8. For these reasons, femtocell and hotspot deployments should be considered complimentary to rather than competitive with macrocells and microcells.

Table 8. Comparison of macrocell/microcell and femtocell/hotspot use models

Macro/microcell	Femtocell/hotspot
Ubiquitous mobile data and voice	Opportunistic nomadic data
Mobility and continuous coverage	Hotspot coverage
Ability to control QoS	Limited QoS for lower value data
Limited capacity and data rates	Distributed cost (not low cost)
High costs, acceptable for high value traffic	Free or charged
Often outdoors and moving	Indoors and sitting down

Fixed wireless customer premises equipment (CPE)

Customer premises equipment in the context of the 3GPP specifications refers to a UE in a fixed location. Two main deployment scenarios are given in TR 36.807, as shown in Figure 14.

The main advantage of the CPE is that it can be optimally located using a higher performance antenna, and it is defined with a higher output power of up to 27 dBm compared with 23 dBm for a standard UE. Customer premises equipment is also less likely to be battery powered, which gives added design freedom to optimize radio performance. The indoor scenario will likely involve an omni-directional antenna whereas the outdoor scenario will likely be deployed using some form of directional antenna.

The combination of antenna positioning, output power, fixed location, and less concern about power consumption dramatically changes the performance that would be possible using a typical mobile UE. This extra radio performance is particularly useful where LTE might be used to provide high performance broadband services; for example, in rural areas. Such deployment is seen as an attractive use of the "digital dividend" spectrum freed up by the switchover from analog to digital television.

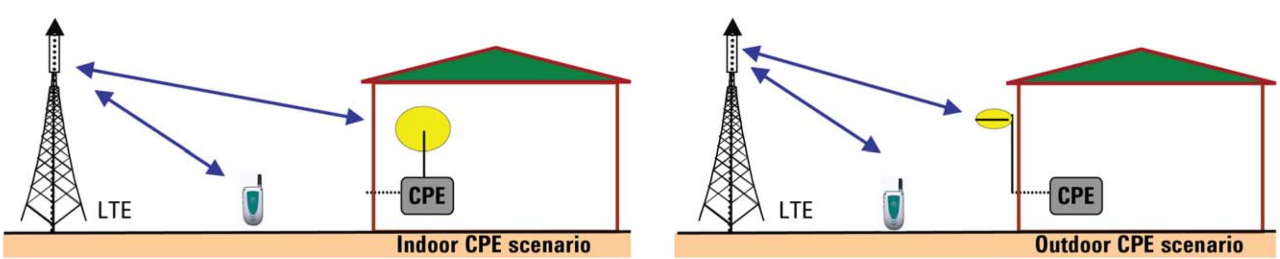


Figure 14: CPE deployment scenarios (36.807 Figure 9.2-1) [21]

Design and Test Challenges

As an evolution of LTE, LTE-Advanced and Release 10 will pose many challenges to engineers. The LTE standard is new and quite complex, with multiple channel bandwidths, different transmission schemes for the downlink and uplink, both frequency and time domain duplexing (FDD and TDD) transmission modes, and use of MIMO antenna techniques. LTE and LTE-Advanced will have to co-exist with 2G and 3G cellular systems for some time, so interworking necessities and potential interference remain important issues. In typical difficult radio environments, LTE sets the bar for performance targets very high, and LTE-Advanced raises it even higher.

Carrier aggregation

Although not considered a problem for the base station, carrier aggregation will undoubtedly pose major difficulties for the UE, which must handle multiple simultaneous transceivers. The addition of simultaneous non-contiguous transmitters creates a highly challenging radio environment in terms of spur management and self-blocking. Simultaneous transmit or receive with mandatory MIMO support will add significantly to the challenge of antenna design.

The exact impact of carrier aggregation on the specifications depends on the reference UE architecture, and several are still under discussion. Until this discussion is concluded, the performance requirements for carrier aggregation remain to be decided.

Creating carrier aggregation signals

To illustrate the concepts of carrier aggregation some examples are provided here using Agilent's SystemVue design software, which can be used for high level system design and verification.

Various options exist for implementing carrier aggregation in the transmitter architecture depending primarily upon the frequency separation, which heavily influences where the component carriers are combined:

- at digital baseband
- in analog waveforms before the RF mixer
- after the RF mixer but before the power amplifier (PA)
- after the PA

Figure 15 shows some of these possible transmitter architectures for the UE.

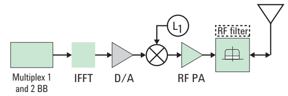
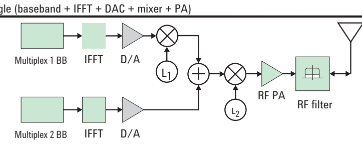
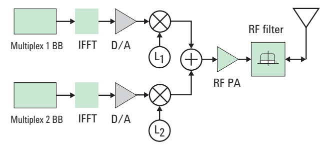
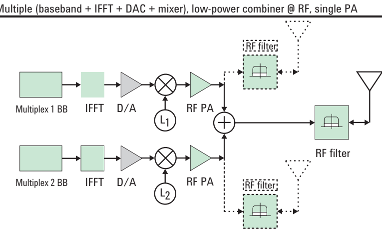
Tx Characteristics				
Option	Description (Tx architecture)	Intra Band aggregation		Inter Band aggregation
		Contiguous (CC)	Non contiguous (CC)	Non contiguous (CC)
A	 Single (baseband + IFFT + DAC + mixer + PA)	Yes		
B	 Multiple (baseband + IFFT + DAC), single (stage-1 IF mixer + combiner @stage-2 RF mixer + PA)	Yes	Yes	
C	 Multiple (baseband + IFFT + DAC + mixer), low-power combiner @ RF, single PA	Yes	Yes	
D	 Multiple (baseband + IFFT + DAC + mixer + PA), high power combiner to single antenna OR dual antenna	Yes	Yes	Yes + (depending on specific EUTRA bands being aggregated)
X	OTHER			

Figure 15. Possible UE transmitter architectures for various carrier aggregation scenarios (36.912 V9.3.0 2010-06 Fig. 11.3.2.1-1)

All of the transmitter architectures illustrated in Figure 15 can be implemented easily in Agilent SystemVue software. Figure 16 shows a quick implementation of LTE Advanced sources with carrier aggregation.

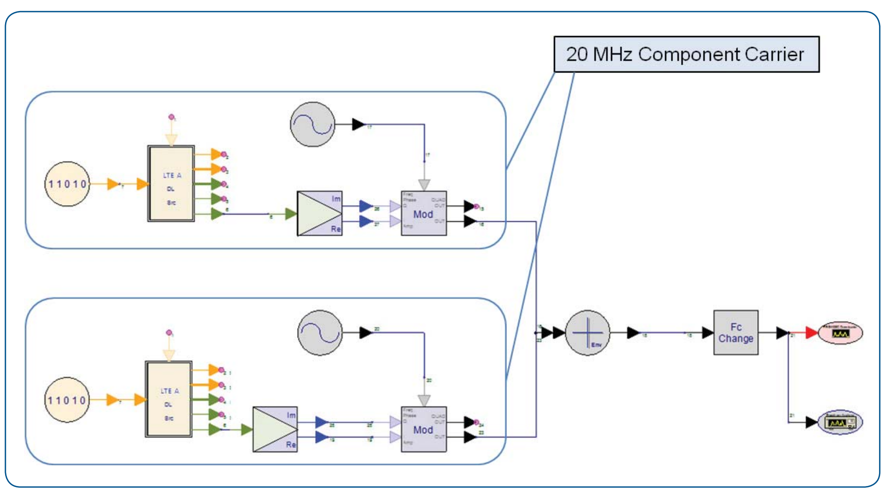


Figure 16. Example of intra-band carrier aggregation in Agilent SystemVue

Figure 16 is an example of intra-band contiguous carrier aggregation. The structure assumes that each component carrier is processed by an independent signal chain. This structure could also be applied to non-contiguous carrier aggregation for both intra-band and inter-band.

Figure 17 shows the spectrum of two 20 MHz component carriers chosen from Band 7 (2600 MHz) are aggregated with the center frequency spacing set to 20.1 MHz (a multiple of the required 300 kHz). Figure 18 shows the constellation of the physical channels and physical signals in the first component carrier (2630 MHz).

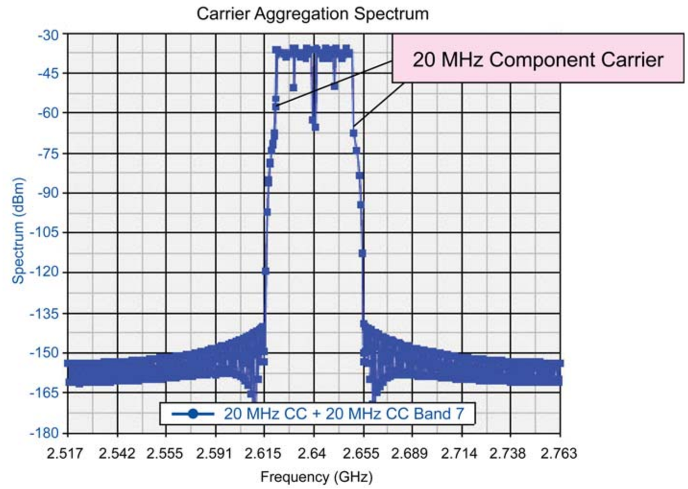


Figure 17. Carrier aggregation spectrum of two adjacent component carriers

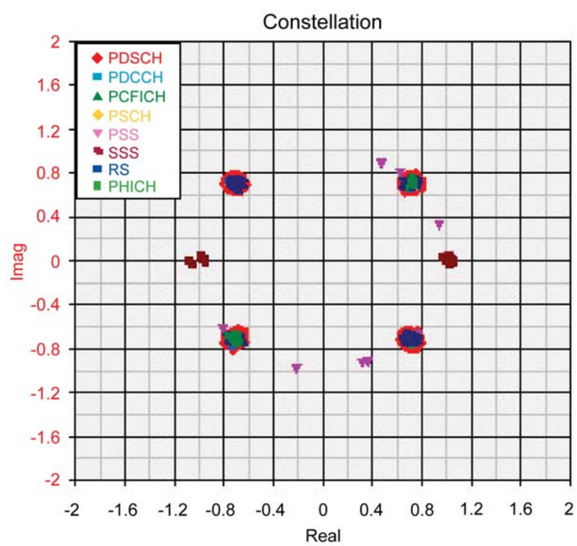


Figure 18. Constellation of the first component carrier

In Figure 19, four adjacent 20MHz component carriers chosen from 3.5 GHz are aggregated with the adjacent center frequency spacing set to 20.1 MHz.

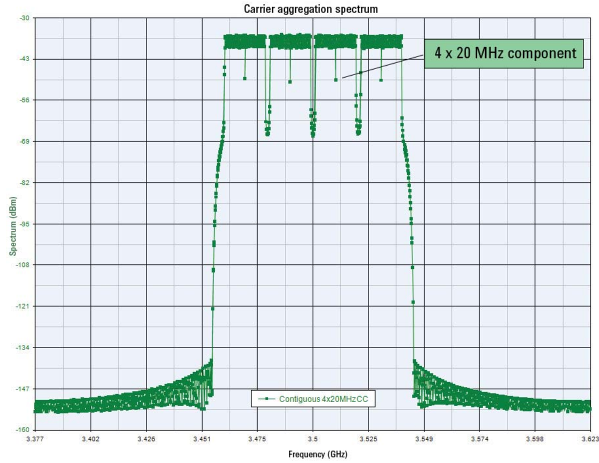


Figure 19. Carrier aggregation spectrum of four component carriers

Enhanced uplink multiple access

The introduction of clustered SC-FDMA in the uplink allows frequency selective scheduling within a component carrier for better link performance. Also, the PUCCH and PUSCH can be scheduled together to reduce latency. However, clustered SC-FDMA increases PAPR by a significant amount, adding to transmitter linearity issues. Simultaneous PUCCH and PUSCH also increase PAPR. Both features create multi-carrier signals within the channel bandwidth and increase the opportunity for in-channel and adjacent channel spur generation. Test tools will need to be enhanced with capability for signal generation and analysis of in-channel multicarrier signals in LTE-Advanced power amplifiers.

Figure 20 shows an example of spur generation caused by simultaneous transmission of two PUCCH signals at the channel edge.

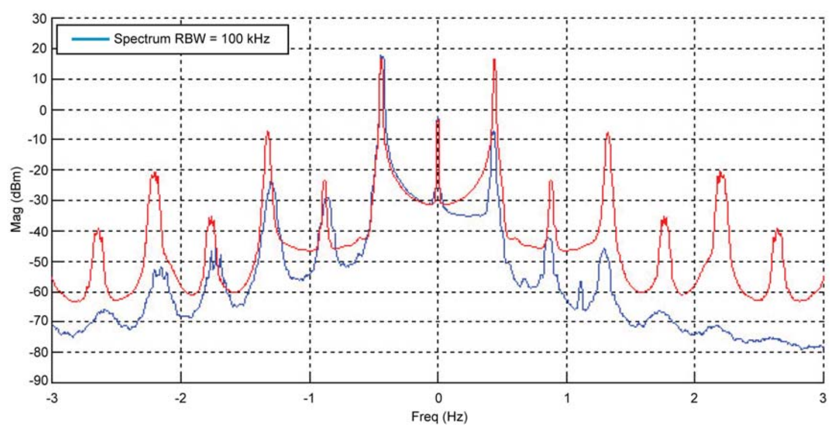


Figure 20. Comparison of spurs generated by two adjacent vs. two channel edge RB [22]

The blue trace shows the spurs generated by two adjacent RB at the channel edge. The red trace shows the increased spurs caused by moving one of the RB to the other edge of the channel to simulate the effect of simultaneous PUCCH. Note that in some places the spurs rise by around 40 dB, which would require either a substantial improvement in power amplifier (PA) linearity or a reduction in the maximum operating level. Until issues relating to spurs are concluded, the extent to which enhanced uplink RF performance requirements will be included in Release 10 remains to be decided.

Designing an enhanced uplink signal

Figure 4 showed a block diagram for clustered SC-FDMA in LTE-Advanced. The implementation of this uplink transmission scheme using Agilent SystemVue models is shown in Figure 21. The input and output of each model can be observed.

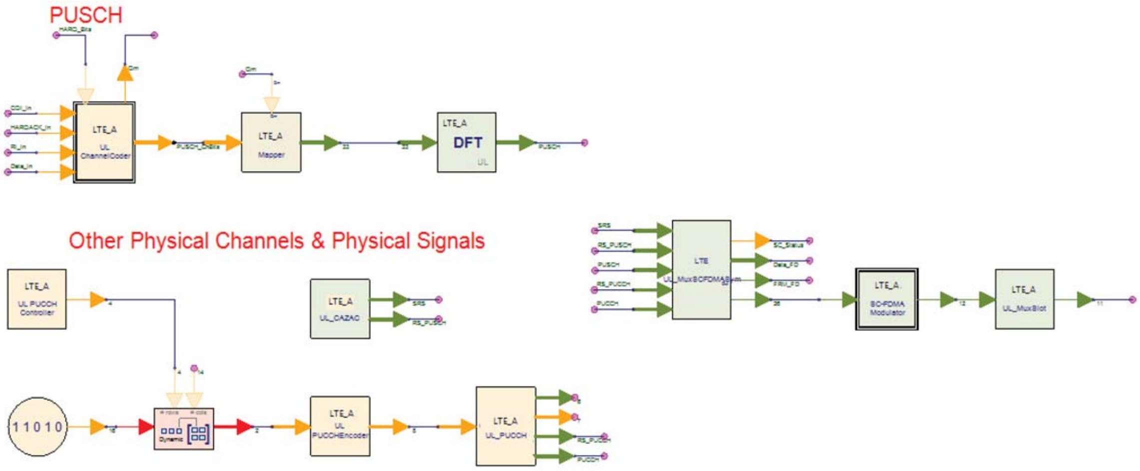


Figure 21. Implementation of clustered SC-FDMA in Agilent SystemVue

Enhanced multiple antenna transmission

Higher order MIMO will increase the need for simultaneous transceivers in a manner similar to carrier aggregation. However, MIMO has an additional challenge in that the number of antennas will multiply, and the MIMO antennas will have to be de-correlated. It will be especially difficult to design multiband, MIMO antennas with good de-correlation to operate in the small space of an LTE-Advanced UE. Conducted testing of higher order MIMO terminals will no longer be usable for predicting actual radiated performance in an operational network. A study item in Release 10 of the 3GPP standard is looking at MIMO over the air (OTA) testing that could be extended to the higher order MIMO defined for LTE-Advanced.

The potential reception gains from MIMO systems are a function of the number of antennas. Although the theoretical potential of such systems can be simulated, practical considerations make commercial deployment more challenging. At the base station, compact 4x antenna systems are already in use. Increasing this to 8x to maximize the potential for spatial multiplexing and beamsteering may require the use of tower-mounted remote radio heads (RRH) to avoid the need to run 8 sets of expensive and lossy cables up the tower. The increased power consumption of MIMO systems is also a factor that cannot be overlooked. There is a trade-off between the number of antennas per sector and the number of sectors per cell. In some circumstances it may be preferable to use a six sector cell with four antennas per sector rather than a three-sector cell with eight antennas per sector.

At the UE, the main issue with higher order MIMO is the physical space required for the antennas. Laptop data-only systems clearly have an advantage over handheld devices in terms of size, power handling, and throughput requirements. In addition, it is very hard in a small device to achieve the necessary spatial separation of the antennas in order to exploit the spatial beamforming in the channel. A common solution to this is to use cross-polarization rather than spatial separation to reduce the correlation between antennas.

Designing enhanced MIMO systems

Figure 22 is an example of an 8x4 LTE-Advanced system designed in Agilent SystemVue. It is an extrapolation of the existing closed-loop spatial multiplexing measurement defined for Release 8 in 36.101 8.2.1.4. The precoding matrix indicator (PMI) is fed back from the receiver to the transmitter and the throughput is calculated from the UE ACK/NACK reports. Different channel models can be used to cover the range of IMT-Advanced operating environments.

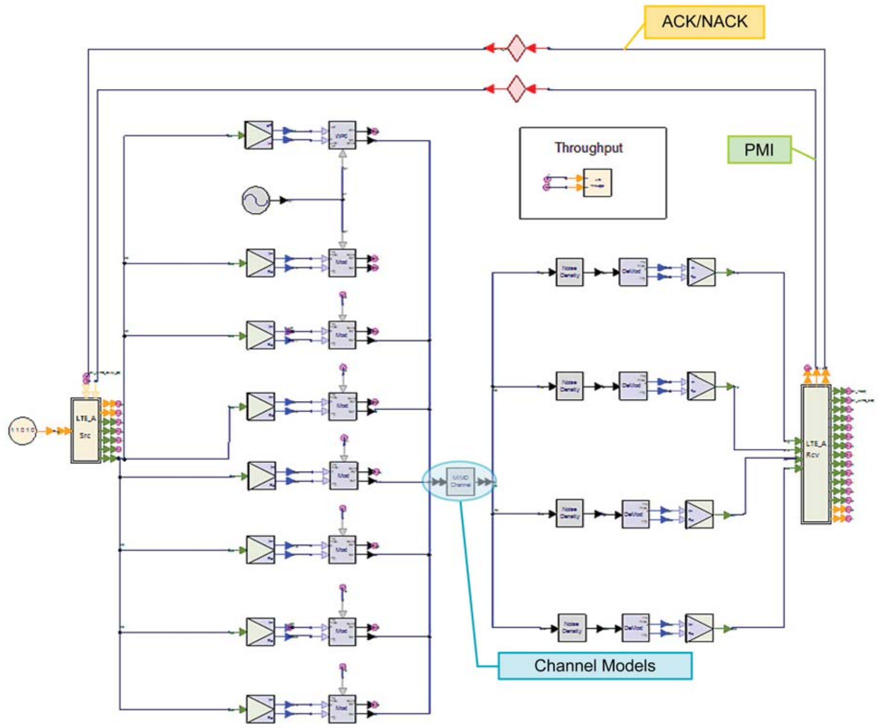


Figure 22. Example of how a DL closed loop spatial multiplexing measurement for Release 8 (36.101 8.2.1.4) could be expanded to 8x4 for LTE-Advanced

More advanced testing of spatial multiplexing performance in realistic conditions can be carried out by including UE CQI reports, which enable the use of adaptive modulation and coding (AMC) on the downlink.

Relaying

From the UE perspective, relaying is completely transparent so the design challenge is all on the network side. For the system to work, the link budget from the RN to the macro eNB must be good, which implies line-of-site positioning. The main operational challenge in getting relaying to work will be in the management of the UE. The UE must be instructed to hand over to a RN that is within range and release the RN when the UE goes out of range. If this process is not well managed, the performance of the cell could actually go down, not up as intended. Managing multi-hop relaying for coverage—for example, in a valley with no cabled backhaul—should be an easier task as no UE is involved.

Summary

These are just a few of the challenges that LTE-Advanced and Release 10 will present wireless design and test engineers. As the 4G specifications are published and the certification process moves ahead, so too will test vendors have to increase the capability of their products and invent ingenious new ways to verify the performance of the evolving 4G systems.

Outlook for LTE-Advanced Deployment

Industry-supported field trials are already demonstrating the viability of many of the technical concepts in LTE-Advanced, and 3GPP's submission to the ITU included a self-evaluation of its proposals concluding that LTE-Advanced meets all 4G requirements for being officially certified as 4G. Nevertheless, the timing of LTE-Advanced deployment is difficult to predict and will be dependent on industry demand and the success of today's Release 8 and 9 LTE rollouts.

From a standardization perspective LTE-Advanced is about two years behind LTE. However, the deployment of LTE-Advanced may be more than two years behind LTE for many reasons. These include the fact that LTE itself will have a slow roll-out due to limited spectrum availability and the continued development and success of 2G and 3G systems. In addition, LTE-Advanced represents a big increase in system and device complexity, and it will take time for the industry to respond.

Design and Test Tools for LTE-Advanced Developers

As the leader in design and test products for LTE and wireless communications, Agilent will provide the tools needed to gain insight into complex LTE technology implementations.

Agilent SystemVue provides early R&D exploration of LTE Advanced features, facilitating the algorithm design and product development of systems based on this emerging new standard. SystemVue is Agilent's electronic design automation (EDA) environment for electronic system level design, focused on the physical layer (PHY) of wireless communication systems. SystemVue enables system architects and algorithm developers to combine signal processing innovations with accurate RF system modeling, interaction with test equipment, and algorithm-level reference IP and applications.

For the 3GPP LTE design community, SystemVue provides math, C++, and graphical algorithmic modeling interfaces, dedicated "golden reference" blocksets for LTE Release 8 (compiled or source code IP), digital pre-distortion, physical 8x8 MIMO channel modeling and fading, and soon LTE-Advanced. With links from concept to hardware generation to test, SystemVue accelerates architectural exploration and model-based design of LTE Advanced Layer 1 systems, also linking to enterprise design flows and reducing overall verification effort. SystemVue is a valuable, complementary environment that provides insight into expected hardware performance well before hardware is physically available, and for transitioning a project from initial inquiry into the standards to product development by cross-domain RF and baseband product teams focused on achieving next-generation system performance.

Agilent's full range of LTE design and test products also includes baseband emulators, signal analyzers, sources, base station emulators, power meters and sensors, logic analyzers, scopes, signal creation software, and much more. For transmitter and receiver testing, the Agilent X-Series signal analyzers and generators with the existing LTE software can create and analyze LTE-Advanced component carriers (CCs), which are compatible with Release 8.

As LTE-Advanced is defined in Release 10 and beyond, Agilent products will be ready to take on the latest test requirements with powerful, standards compliant enhancements and features.

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Acronyms

2G	Second Generation
3G	Third Generation
3GPP	Third Generation Partnership Project
4G	Fourth Generation
ACK/NACK	Acknowledgement/Negative Acknowledgement
AMC	Adaptive Modulation and Coding
ARQ	Automatic Repeat Request
BS	Base Station
BW	Bandwidth
CA	Carrier Aggregation
CC	Component Carrier
CDMA	Code Division Multiple Access
CoMP	Cooperative Multipoint
CPE	Customer Premises Equipment
CQI	Channel Quality Indicator
CRS	Cell-specific Reference Signal
CSG	Closed Subscriber Group
CSI-RS	Channel State Information Reference Signals
DeNB	Donor-cell Enhanced Node B
DFT-S-OFDM	Discrete Fourier Transform Spread Orthogonal Frequency Division Multiplexing
DL	Downlink
DLMA	Downlink Multiple Antenna
DL-SCH	Downlink Shared Channel
DMRS	Demodulation Reference Signal
DSL	Digital Subscriber Line
EDA	Electronic Design Automation
E-DCH	Enhanced Dedicated Channel
EDGE	Enhanced Data Rates for GSM Evolution
eNB	Evolved Node B
EPA	Extended Pedestrian-A
E-UTRA	Evolved Universal Terrestrial Radio Access
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
FDD	Frequency Division Duplex
GCF	Global Certification Forum
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communication
HARQ	Hybrid Automatic Repeat Request
HeNB	Home eNB
HSCSD	High Speed Circuit Switched Data
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access
HSUPA	High Speed Uplink Packet Access
ICIC	Inter Cell Interference Cancellation
IMT	International Mobile Telecommunications
IMT-Advanced	International Mobile Telecommunications Advanced (4G)
IMT-2000	International Mobile Telecommunications 2000 project (3G)
ISD	Inter-Site Distance
ITU	International Telecommunications Union
ITU-R	ITU-Radiocommunications Sector
LCR-TDD	Low Chip Rate Time Division Duplex
LTE	Long Term Evolution

LTE-A	LTE-Advanced
MAC	Medium Access Control
MIMO	Multiple Input Multiple Output
MU-MIMO	Multiple User MIMO
O&M	Operations and Maintenance
OCC	Orthogonal Code Cover
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
PA	Power Amplifier
PAPR	Peak to Average Power Ratio
PCFICH	Physical Control Format Indicator Channel
PDCCH	Physical Downlink Control Channel
PDS	Packet Data System
PHICH	Physical Hybrid ARQ Indicator Channel
PHY	Physical Layer
PMI	Precoding Matrix Indicator
PUCCH	Physical Uplink Control Channel
PUSCH	Physical Uplink Shared Channel
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RAN	Radio Access Network
RB	Resource Block
RF	Radio Frequency
RI	Rank Indicator
RIT	Radio Interface Technology
RN	Relay Node
RS	Reference Signal
RX	Receiver
SAE	System Architecture Evolution
SC-FDMA	Single Carrier Frequency Division Multiple Access
SISO	Single Input Single Output
SON	Self Optimizing Network
SRS	Sounding Reference Signal
SU-MIMO	Single User MIMO
TB	Transport Block
TDD	Time Division Duplex
TD-SCDMA	Time Division Synchronous Code Division Multiple Access
TR	Technical Report
TS	Technical Specification
TTI	Transmission Time Interval
TX	Transmitter
UCI	Uplink Control Information
UE	User Equipment
UL	Uplink
ULMA	Uplink Multiple Antenna
UL-SCH	Uplink Shared Channel
UMTS	Universal Mobile Telecommunications System
UCI	Uplink Control Information
VoIP	Voice over Internet Protocol
W-CDMA	Wideband CDMA
WP	Working Party

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Revised: October 14, 2010

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Printed in USA, November 30, 2010
5990-6706EN

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