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LTE and LTE-Advanced factsheet

The "Long Term Evolution" of UMTS

Summary

LTE (Long Term Evolution) designates the successor to the widespread mobile radio standard UMTS (Universal Mobile Telecommunications System). Its introduction is one of the responses to the rapid growth in mobile data traffic. To date, the volume of traffic transmitted over mobile networks worldwide has doubled every year. In many countries, including Switzerland, this traffic doubling time is just seven months.

LTE includes an air interface optimised for mobile radio which has already proved itself in terrestrial digital broadcasting networks. This requires new equipment in existing and additional base stations and new user devices (mobile phones, tablets, PCs, modems, routers). In addition to a variety of other characteristics, LTE primarily provides higher bit rates on the air interface between base station and user device. This increases the transmission capacity of mobile networks and either more customers can be served at the same bit rate or the same number of end users can be provided with higher bit rates. In addition, the shorter data transmission interval (latency) results in a significantly improved responsiveness of the network. Furthermore, compared to UMTS, in the user device LTE consumes less energy and thereby promotes longer battery life when the data service is activated.

The further development of the air interface is closely linked to the further development of the core network (network of base stations). The further development of the core network is proceeding under the banner of SAE (Services Architecture Evolution). Among other things, LTE and SAE aim to improve the user's experience and reduce the cost per transmitted bit.

This factsheet provides an overview of the new LTE air interface, its future evolution and insights into network structure and services, without claiming to be exhaustive.

Contents

1 Abbreviations

3GPP	3rd Generation Partnership Project
AIPN	All-IP Network
AMC	Adaptive Modulation and Coding
APN	Access Point Name
BAKOM	Federal Office of Communications
bps	Bits per second
CDMA	Code Division Multiple Access
DECT	Digital Enhanced Cordless Telecommunications
DSL	Digital Subscriber Line
DVB-T	Terrestrial Digital Video Broadcast
eMBMS	Evolved Multimedia Broadcast/Multicast Service
EDGE	Enhanced Data Rates for GSM Evolution
EPC	Evolved Packet Core
EPS	Evolved Packet System (EPS = E-UTRAN + EPC)
E-UTRA	Evolved UMTS Terrestrial Radio Access
E-UTRAN	Evolved UMTS Terrestrial Radio Access Network
EV-DO	Evolution-Data Optimized
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
FTTx	Fibre To The x (Home, Building, Curb …)
GBR	Guaranteed Bitrate
GHz	Giga-Hertz (10^9 Hertz)
GSM	Global System for Mobile Communications
HetNet	Heterogeneous Network
HSPA	High Speed Packet Access
ICIC	Inter Cell Interference Coordination
IEEE	Institute of Electrical and Electronics Engineers
IMS	IP Multimedia System
IMT	International Mobile Telecommunications
IP	Internet Protocol
ITU	International Telecommunication Union
ITU-R	ITU Radiocommunication Sector
LIPTO	Local Internet Protocol Traffic Offload
LTE	Long Term Evolution
LTE-A	LTE-Advanced
MBMS	Multimedia Broadcast/Multicast Service
MHz	Mega-Hertz (10^6 Hertz)
MIMO	Multiple Input Multiple Output (multiple antenna technique)
OFCOM	Federal Office of Communications
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
PER	Packet Error Rate
PRB	Physical Resource Block
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service

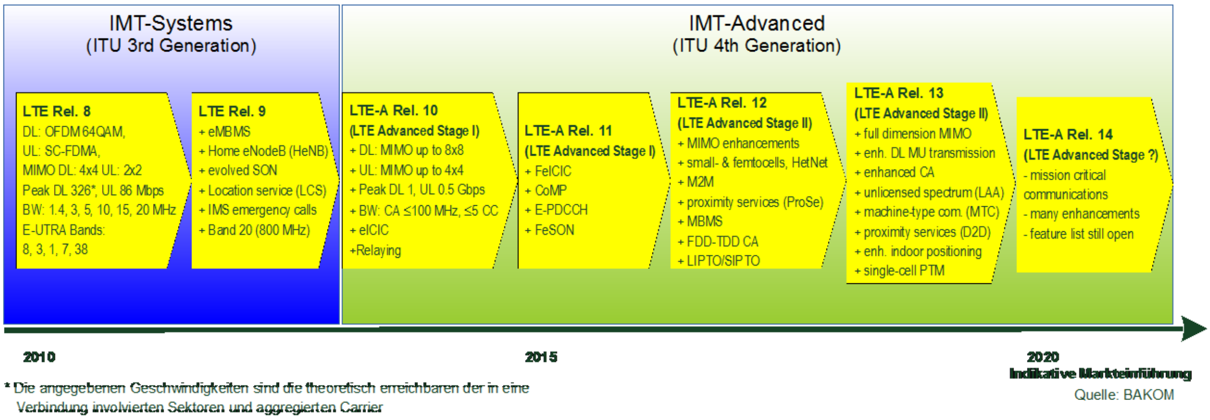
QPSK	Quadrature Phase-Shift Keying
RAT	Radio Access Technology
RB	Resource Block
RRM	Radio Resource Management
SAE	Services Architecture Evolution
SC-FDMA	Single Carrier Frequency Division Multiple Access
SDMA	Space Division Multiple Access
SFN	Single-Frequency Network
SIPTO	Selected Internet Protocol Traffic Offload
SIR	Signal to Interference Ratio
SMS	Short Message Service
SON	Self Organising Network
TDD	Time Division Duplex
TTI	Transmission Time Interval
UMTS	Universal Mobile Telecommunications System
UTRAN	UMTS Terrestrial Radio Access Network
VoIP	Voice over IP
VoLTE	Voice over LTE
WiMAX	Worldwide Interoperability for Microwave Access
WRC	World Radio Conference (ITU)

2 Overview

Various independent market studies predict a rapid increase in mobile data traffic by 2030. Data traffic in mobile networks around the world has to date doubled approximately every year and in several countries this increase is even more pronounced. Such growth in traffic cannot be handled merely by providing new mobile radio frequencies. Spectrum efficiency must be improved as well as the density of radio cells.

To meet the needs for higher capacities and higher data rates and to ensure greater spectrum efficiency, the new mobile radio system known as Long Term Evolution (LTE) has been developed by the industry. The LTE standard is linked to the 3GPP technologies (UMTS, HSPA, HSPA+) and represents a further development of these. LTE's goal was 3 to 4 times higher spectrum efficiency than UMTS/HSPA (High Speed Packet Access) – at relatively lower network costs (i.e. lower costs per transmitted bit).

The market introduction of LTE dates from 2010, as Figure 1 shows.



The indicated speeds are the maximum theoretically achievable on a connection in the involved sectors and aggregated carriers

Indicative market introduction. Source: OFCOM

Figure 1: Chronological introduction of LTE standard releases with features

According to the requirements of the ITU-R for the air interfaces, the UMTS, HSPA, HSPA+ and LTE technologies belong to the 3rd generation (3G) mobile radio systems. LTE is therefore also described as “3.9G” or “3.99G”. The term LTE includes releases 8 and 9 of the standard. The further development of LTE is termed LTE-Advanced (LTE-A) and is taking place in two phases. LTE-A Phase 1 includes releases 10 and 11 and LTE-A Phase 2 releases 12 and 13 of the standard. LTE-A meets the requirements of the ITU-R for 4th generation (4G) air interfaces and is termed IMT-Advanced. The development of release 12 was concluded in mid-2015.

In early 2011 approximately 15 LTE commercial networks were in operation in 11 different countries worldwide. At the beginning of 2011, eight commercial LTE networks were in operation in Western Europe and several more were announced.

In Switzerland, the first commercial commissioning of an LTE network took place at the end of 2012, the third and to date the latest commissioning was in mid-2013. Since then the LTE networks have been continuously expanded and upgraded. In the first quarter of 2015, coverage of the Swiss population was over 92% for at least two of the three operators.[1]

According to the Global Suppliers Association (GSA), in April 2015 some 393 networks were in commercial operation worldwide (including 54 LTE TDD)[2] worldwide and a further approx. 200 operators were intending to construct an LTE network (see Figure 2).

With some 7 billion current users worldwide (potentially LTE-capable SIM cards or connection contracts) according to the 3GPP standards, LTE has clearly prevailed over

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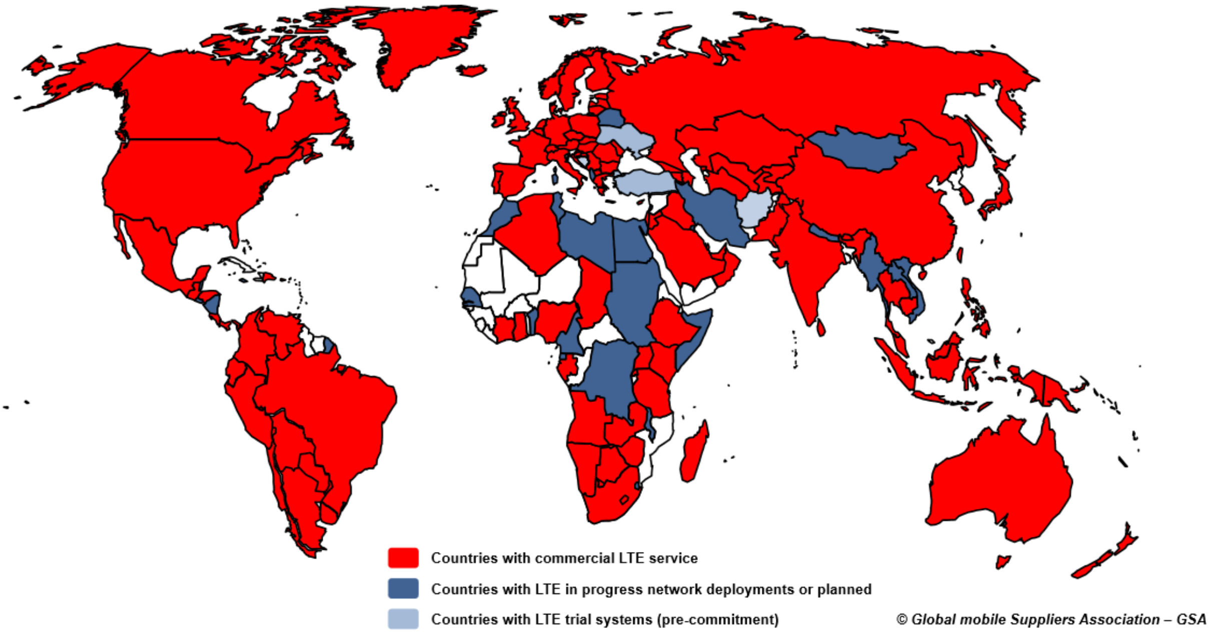
[1] Operator information, requested in May 2015

[2] http://www.gsacom.com/downloads/pdf/Snapshot_LTE-TDD_extract_GSA_Evolution_to_LTE_report_090415.php4

competing mobile radio standards such as CDMA2000/EV-DO or IEEE/WiMAX (see Figure 9).



Source: www.gsascom.com[3]

Figure 2: Commercial and planned LTE networks worldwide – as of May 2015

The LTE standard supports all mobile radio frequencies. LTE was first introduced in the E-UTRA band 3 (1800 MHz), which was used and continues to be used by GSM (seeTable 1). This was the beginning of the gradual substitution of GSM by LTE. The choice of band 3 for the introduction of LTE initially required no additional antenna panels at base stations for network operators. These would have been necessary in the event of selection of new frequency bands such as 20 or 7 (800 MHz, 2.6 GHz). In addition, band 3 with 2 x 75 MHz bandwidth provides sufficient capacity for assignment between GSM and LTE. Because of the high degree of flexibility multi-RAT-capable base stations are used; these can support all mobile radio technologies (GSM, UMTS/HSPA+, LTE-x) and make these available for use statically or dynamically depending on demand. Some of the first user devices already supported frequency bands 20 and/or 7 (see Table 1).

Unlike UMTS, in the case of LTE user devices, both techniques are used as standard for simultaneous[4] data communication from the base station to the user device and vice versa: frequency-division duplex FDD and time-division duplex TDD. Many user devices support both duplex techniques. This permits the exploitation of benefits of scale in the production of terminal components and user devices. As a result, the end user acquires the possibility of world-wide roaming on networks using different duplex techniques and network carriers acquire potentially more usable spectrum.

[3] http://www.gsacom.com/downloads/pdf/Snapshot_LTE-TDD_extract_GSA_Evolution_to_LTE_report_090415.php4

[4] at least approximately

3 Frequencies and licences

In February 2012 the Federal Communications Commission ComCom auctioned all the mobile radio frequencies available at that time[5]. All 5 MHz frequency blocks from the frequency bands specified in Table 1 were acquired by auction by the three existing Swiss mobile radio operator companies. The proceeds for the Confederation from the auction amounted to approximately CHF 996 million.

Frequency band	E-UTRA operating bands	Bandwidth	Duplex technique	Supported from LTE release
800 MHz	20	2x30 MHz	FDD	9
900 MHz	8	2x35 MHz	FDD	8
1800 MHz	3	2x75 MHz	FDD	8
2100 MHz	1	2x60 MHz	FDD	8
2600 MHz	7 38	2x70 MHz 1x45 MHz	FDD TDD	8
	Total	**585 MHz**		

Table 1: Frequency bands for LTE in Europe

In many countries on all continents, additional mobile radio bands are planned for IMT systems in the 700 MHz, 1400 MHz and 3.5 GHz ranges with a total potential gross bandwidth of up to 525 MHz. The decision in this context will be taken at the World Radio Conference [6] WRC-15 in November 2015. It will then be decided whether frequency bands between approx. 6 GHz and 100 GHz are also to be used for IMT.

4 Technology of the LTE air interface

4.1 Overview

From 2005 onward, 3GPP had defined the requirements for LTE and LTE Advanced, based on the requirements of the ITU-R for IMT-2000 and IMT-Advanced. The most important initial technical performance goals for LTE were:

- a significant increase in the data rate on the downlink up to 100 Mbit/s in the 20 MHz bandwidth, i.e. an increase in spectrum efficiency of up to theoretically 5 bit/s/Hz with one transmission antenna and two receiving antennas (this corresponds to 3 to 4 times the spectral efficiency of UMTS/HSDPA Rel. 6.
- a significant increase in the data rate on the uplink of up to 50 Mbit/s in the 20 MHz bandwidth, i.e. an increase in spectrum efficiency of up to theoretically 2.5 bit/s/Hz with one transmission antenna and two receiving antennas (this corresponds to 3 to 4 times the spectral efficiency of UMTS/HSDPA Rel. 6).
- Flexible spectrum use by scalable channel bandwidths of 1.4 MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz and 20 MHz
- The delay time across the air interface from the user device to the base station must be less than 5 ms. Round-trip delay must be less than 10 ms
- Flexible spectrum use by means of FDD and TDD duplex techniques
- Higher data rates at the periphery of the cell than with UMTS
- Mobility up to 500 km/h (optimised for 0 – 15 km/h)
- Support for different QoS and mobility requirements
- Integration of MIMO into the standard
- Low transmission costs per bit across the air interface
- Simple scalable architecture, fewer network elements, open interfaces
- The lowest possible power consumption of user devices (long battery life)

[5] http://www.comcom.admin.ch/themen/00783/index.html?lang=de

[6] http://www.itu.int/en/ITU-R/conferences/wrc/2015/Pages/default.aspx

The most important innovations in the core network include the flat, decentralised architecture based on the Internet Protocol and the elimination of circuit switching. Purely packet-switched networks are all IP networks (AIPN). The principle feature is the substantially flatter hierarchy of the network elements than that exhibited by circuit-switched networks (2G and 3G). The goal of this architecture is reduction of costs with flexible scalability (see Chapter 5 and 6).

The most important innovations of the LTE air interface LTE are the introduction of

- OFDM (Orthogonal Frequency Division Multiplexing) modulation and the OFDMA (Orthogonal Frequency Division Multiple Access) channel access procedure on the Downlink,
- SC-FDMA (Single Carrier – Frequency Division Multiple Access) on the Uplink,
- plus scalable channel bandwidths.

SC-FDMA is a method which is used with OFDMA. This technique allows operation of the system with scalable channel bandwidths; a range from 1.4 MHz to 20 MHz has been chosen. This means that LTE can be used flexibly in the respective assigned bandwidths and unlike UMTS it does not presuppose a continuous block of at least 5 MHz or a multiple thereof.

Flexible channel bandwidths permit gradual refarming[7] of the existing infrastructure and networks, plus use in fragmented frequency assignments, such as those that exist as a result of coordination at the national frontiers, for example in the case of GSM preference frequencies.

The technology behind LTE is complex: A very strict and agile allocation of the carrier signals in the time and frequency domain gives LTE an efficiency advantage over the air interfaces used to date in public mobile radio networks.

With LTE, the radio parameters with the new OFDMA and SC-FDMA channel access procedures can be adapted within the cycle of the one-millisecond transmission time interval (TTI) in an agile manner to the current characteristics of the radio channel (see Figure 2).

Time ↑

	User 2	User 2		User 1		User 2		
User 3	User 2		User 2		User 3	User 2	User 3	User 2
User 1	User 2	User 3	User 3	User 3	User 1	User 3	User 3	
User 1	User 2	User 3	User 1	User 2				

Frequency →

Figure 2: Example of the distribution of time/frequency resource blocks across 3 users

This distribution is performed by a scheduler algorithm in the base station, which handles resource allocation. To this end, the user device transmits measured values to the base station on the appropriate control channel. In response, the base station signals resource allocations to the radio cell's user devices on the corresponding control channel. The scheduler algorithm, however, is not standardised; but representation of the measured values and protocols on the air interface are already standardised.

With LTE Release 8/9, for the first time, the threshold of 100 Mbit/s on the downlink was exceeded: the new mobile standard – at least in theory – promises maximum data rates of up to 326 Mbit/s on the downlink and 86 Mbit/s on the uplink. With LTE Release 10/11 up to 1 Gbps on the downlink and up to 500 Mbps on the uplink can theoretically be achieved. This increase is achieved primarily by means of multi-antennas through the use of space division multiplexing (SDMA) (see Section 0 and 4.6). Up to 8 antennas can be used on the base station and user devices (8x8 MIMO) on the downlink and up to four antennas in the base station and user devices on the uplink (4x4 MIMO).

Even in the initial construction phase, data rates of up to 100 Mbit/s were possible. LTE promises not only significantly higher data rates and better spectrum efficiency than its predecessors, but also shorter latency (elapsed time of a data packet from transmitter to receiver). For LTE, the latency is a maximum of 5 milliseconds; with UMTS the average latency time is 70 to 140 milliseconds. The delay jitter has also been reduced with LTE.

[7] Refarming means the migration from one radio technology to another, usually from an older one to a newer one.

For real-time services such as VoIP and gaming, a short latency and a small latency fluctuation are a pre-condition for correct functioning. Therefore the time required for a handover between radio cells also had to be greatly reduced. The EPS and the flat network hierarchy of the core network also contributed to this. The network's increased reactivity is crucial for the perceived speed; a high data rate alone is not sufficient for this experience. Compared to UMTS, LTE is expected to favour consumption of video content[8].

As a result of improvements in MBMS, in future LTE is expected to be positioned as a platform for the broadcasting of radio services on mobile radio networks. From Release 10 the ongoing development of eMBMS will be termed "LTE-Broadcast" and has the potential in some markets to become an alternative to DVB-T and other broadcasting technologies.

4.2 Downlink

OFDMA (Orthogonal Frequency Division Multiple Access) has been chosen for the downlink for LTE. OFDMA is the application of OFDM for a multi-access procedure. In contrast to OFDM, with OFDMA blocks of individual sub-carriers are assigned to a user at a specific point in time (seeFigure 2).

This resource assignment takes place in rapid succession (1 ms) and is therefore highly agile. These (sub-carrier) frequency/time slots are termed "Physical Resource Blocks" (PRB). Further details of the structure and parameters can be found in the box.

Compared to other broadband systems, the OFDM receivers are substantially simplified because correction of the channel distortions is comparatively simple to implement. One important reason for the selection of OFDM was the requirement of frequency utilisation in variable bandwidths from 1.4 MHz to 20 MHz. For relatively narrow bandwidths and high bit rates, CDMA ceases to be advantageous.

A further advantage of OFDM on the downlink is the comparatively simple structure of single frequency networks (SFN), i.e. the use of the same frequency in directly contiguous cells. Single frequency networks are especially efficient for transmission of broadcast services using eMBMS. The downlink-only use of TDD frequency ranges and new downlink-only frequency ranges are related to the traffic asymmetry driven by video streaming. Increasing video consumption leads to traffic asymmetry between downlink and uplink. The observed asymmetries (DL in relation to UL) in 2012 yielded factors between 7 and 11.

One disadvantage of OFDM is the stringent requirement for linearity of the transmission amplifier. This is due to a process-determined high peak-to-average power ratio (PAPR) of the modulation signal. Amplifiers with high linearity have a relatively high power consumption and are more expensive. Both aspects mean higher acquisition and operating costs for a base station, but the advantages of simpler user devices outweighs this.

Other radio parameters of the LTE downlink

The resource blocks (PRB) consist of 12 OFDM sub-carriers each of 15 kHz and therefore a bandwidth of 180 kHz for the time of one slot, 0.5 ms.

Seven symbols constitute a slot; a resource block consists of at least 84 symbols. Two slots (14 symbols) together constitute a subframe, defining the minimum transmission time interval (TTI) of 1 ms. A radio frame consists of 10 sub-frames (20 slots) and lasts 10 ms.

The subcarrier modulation types which are used are QPSK, 16 QAM and 64 QAM with 2, 4 and 6 bits/symbol. The choice of modulation type (AMC) is made dynamically by means of selective scheduling by the scheduler algorithm in the radio resource control (RRC) on the basis of the current characteristics of the radio channel signalled by the user device. The minimum scheduling resource consists of 2 resource blocks. Frequency hopping can take place on the basis of the slots.

In the final analysis, these characteristics of LTE allow highly flexible adaptation to

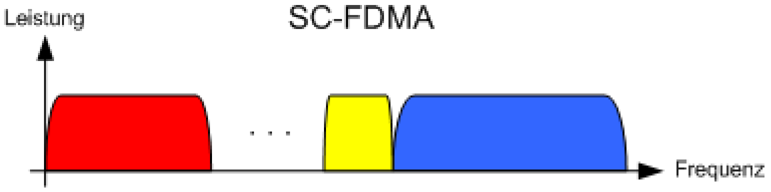
- environments (indoor, urban, suburban, rural),
- different mobility conditions (from stationary/roaming up to 500 km/h)

[8] http://business.chip.de/news/LTE-Treiber-fuer-mobile-Netflix-und-Co._72556383.html

- hotspot cell radii from (ten metres up to several tens of kilometres)
- frequency bands from 400 MHz to 4 GHz

4.3 Uplink

For the uplink, a single-carrier frequency-division multiple access (SC-FDMA) technique was chosen. Advantages of this technique are the relatively low adjacent channel power values, even with a power amplifier of limited linearity. SC-FDMA does not make particularly high demands of the linearity of the user device transmission amplifier thereby reducing power consumption. High power consumption would be a major disadvantage in battery-powered user devices; this is elegantly circumvented by the choice of SC-FDMA. The power consumption of a user device with SC-FDMA is about three times lower than OFDM for the same bit error rate.



Power Frequency

Figure 3: Schematic representation of the transmission spectrum on the uplink. **The different colours represent the occupied spectrum of the individual users.**

With SC-FDMA, a relatively complex equaliser (EQ) is required at the receiver in the base station. SC-FDMA is less sensitive to carrier frequency anomalies than OFDMA. A significant element of the complexity of the uplink has therefore been shifted to the base station, in favour of lower-cost, more energy efficient user devices. The SC-FDMA multiple access technique on the uplink is an innovation in the world of mobile radio.

Each user is allocated a portion of the uplink frequency channel for a certain time by the base station. This allocation takes place in time intervals (TTI) of one millisecond on the downlink (Figure 2).
Power Frequency

Figure 3 shows an example of the received signal in the base station from three users.

In a manner similar to OFDM, the data is distributed across subcarriers, with a Fourier transform (FT) used as pre-equalisation. Consequently, with SC-FDMA, one refers to quasi-subcarriers. The quasi-sub-carriers used by a specific user are always positioned directly contiguous to one another and thus form a single block. Thus the individual users are modulated on their own carrier frequency (a "single carrier") within the uplink channel. The combination of several users on the Uplink results in a simple frequency multiplex multi-access procedure (FDMA) as shown in Power
Frequency

Figure 3 . The distribution of the quasi-subcarriers to the users is chosen by the scheduler (see 4.1) so that at any given time only one active user device in the same cell occupies the same block of subcarriers.

4.4 Spectral efficiency

The evolution of the average spectral efficiency in a radio cell on the downlink using the different mobile radio technologies and Releases is shown in Figure 5. Spectral efficiency is a measurement of the transmission capacity of an air interface in bits per second per Hertz bandwidth per cell (bit/s/Hz/cell) which is shared by all users within a radio cell.

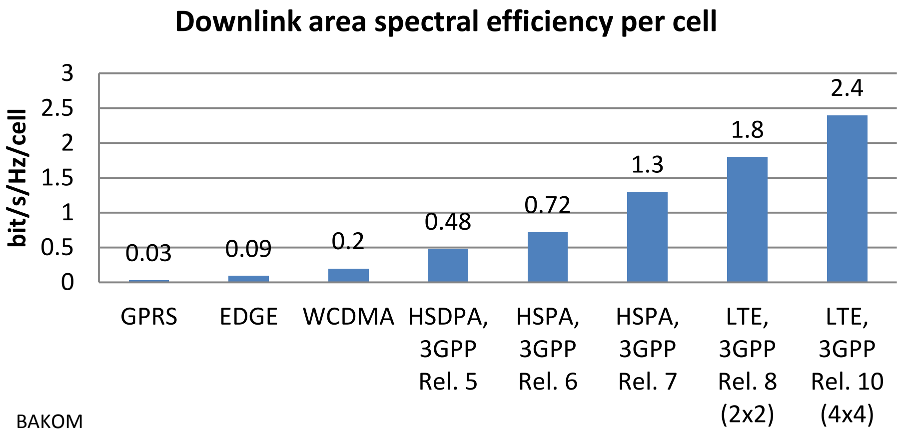


Figure 4: Spectral efficiency of different mobile radio technologies (3GPP)

Example of spectral efficiency: The bandwidth of a radio channel is 5 MHz and the average spectral efficiency is 1.8 bit/s/Hz/cell with two transmission and reception antennas respectively (MIMO 2x2). The *average* transmission capacity C with which all users of this radio cell are supplied by the 5 MHz wide radio channel is accordingly 9 megabits per second on the downlink:

$$C = 5\,MHz \cdot 1.8 \frac{bit}{s \cdot Hz} = 5 \cdot 10^6 Hz \cdot 1.8 \frac{bit}{s \cdot Hz} = 9 \cdot 10^6 \frac{bit}{s} = 9\,Mbps$$

With a 10 MHz wide radio channel, everything else being equal, double the *average* transmission capacity would be available, i.e. 18 Mbps. The average transmission capacity per user must be distinguished from this; it is dependent on the user's quality of reception and/or the congestion caused by other users.

The *maximum* spectral efficiency or *maximum* transmission capacity, however, serves marketing purposes and demonstration of the efficiency of a system in the long run is less relevant in practice.

4.5 Carrier aggregation

Starting from LTE Release 10, up to 5 contiguous channels respectively within one frequency band (intra-band contiguous) can be aggregated in the up and downlink (Figure 5). The number of aggregated carriers may differ in the uplink or downlink. The aggregated channels are made available to the higher network layers by the system logically as a single channel, with correspondingly higher capacity.

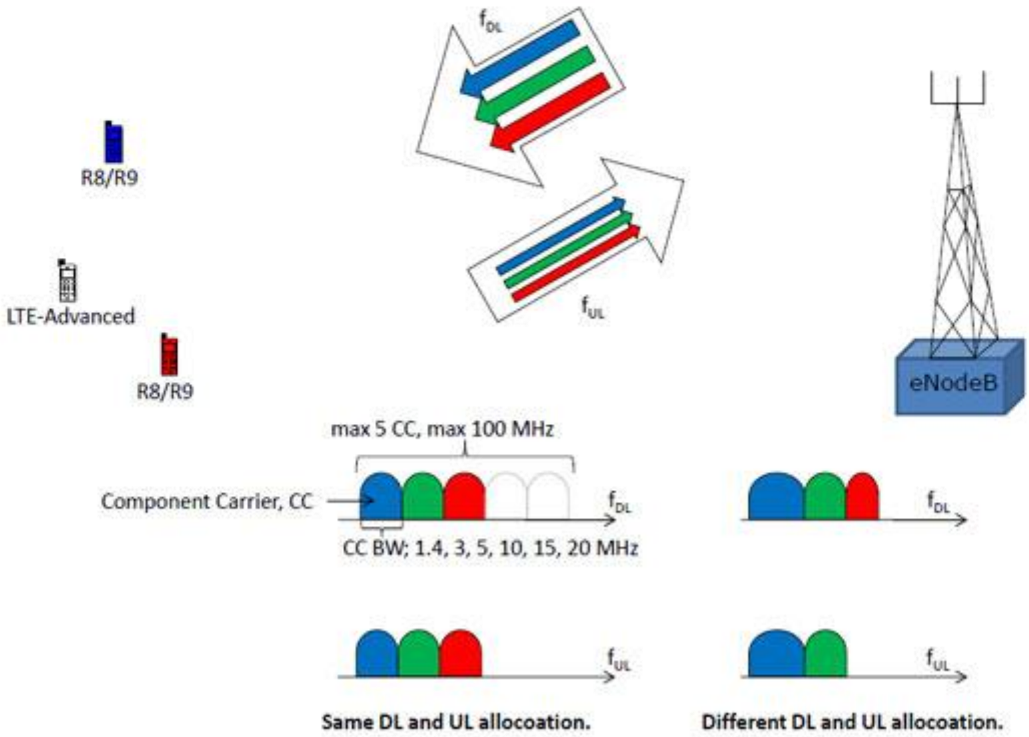


Figure 5: Carrier aggregation from LTE Release 10

Starting from LTE Release 11 a different number of up to 5 channels can likewise be aggregated on the downlink and uplink but from the same or different frequency bands (inter-band non-contiguous), see Figure 7. [7]

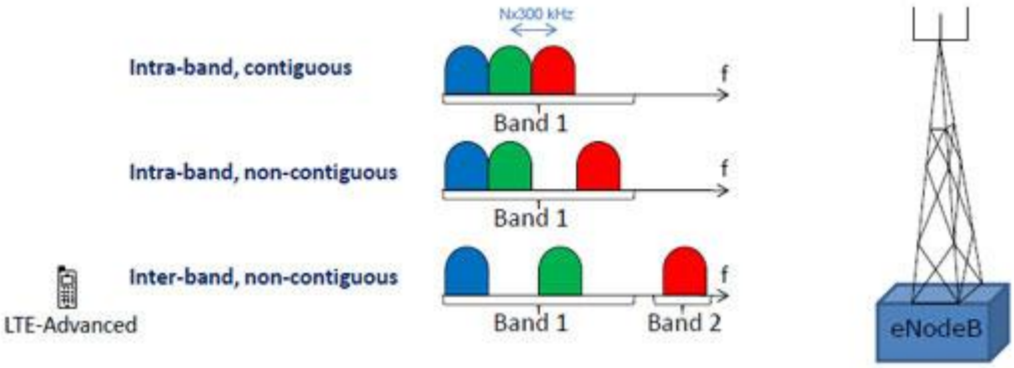


Figure 6: Carrier Aggregation from LTE Release 11

4.6 MIMO

MIMO antenna systems play an important role in LTE. Spectrum efficiency can be increased through the use of smart antennas. In LTE, MIMO antenna systems are an integral part of the standard in the base station and the user device. This is not applicable to UMTS.

MIMO allows parallel transmission of data with multiple antennas at the transmitter and the receiver on the same frequency and at the same time, through the use of multiple antennas in the send and receive direction. Various MIMO applications are envisaged for LTE. These can be broadly divided into the following groups: multiplex (space-multiplex), space diversity, beamforming (BF) or a suitable hybrid form of these. Where and when which form of MIMO will be used depends on the QoS requirements of the service (Chapter 6), the data rate, the condition of the mobile radio channel and the facilities of the user device or device class. The schematic principle is shown in Figure 7.

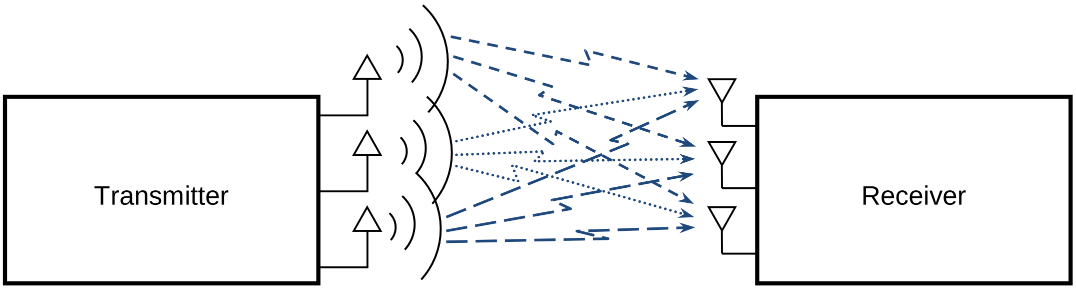


Figure 7: Principle of multi-antenna transmission with MIMO (3x3)

Space diversity enables a significant improvement in the quality of the radio channel in the event of strong and fast fading. The feedback information from the user device to the base station allows the latter to optimally allocate the time/frequency resources (PRB) to a specific link. The channel resources (PRB) can be allocated, depending on the scheduler algorithm, to those users who enjoy the best current transmission channel conditions (Multi User Space Diversity). This maximises the average data throughput per user, as less valuable data transmission time is used by momentarily poor transmission channels. A few milliseconds later the link will be better, with some degree of probability. Accordingly, the technique generally exploits rapidly varying transmission quality cleverly, without the end user being aware of this.

Space multiplex, on the other hand, enables a very high data rate to be achieved, provided that the radio channel is of good quality – i.e. a high average received power, a high signal-to-interference ratio (SIR) and a low correlation between the individual antennas. Space multiplex can be sub-divided into single-user space multiplex and multi-user space multiplex. The system throughput in both cases is the same. With *single-user* space multiplex, the parallel data streams from the different transmitting antennas are transmitted from the base station to a single user. The number of data streams depends on the MIMO antenna configuration. With a 4x4 MIMO (4 transmitting and receiving antennas), for example, four times the data rate, compared to a conventional antenna system (1x1), can theoretically be achieved. With multi-user *space* multiplex, the data streams from the base station are split among various users (SDMA). With a 4x4 MIMO, for example, a total of four users can be served by the same resource (PRB) in the downlink. In this example, therefore, the individual user's data rate is only a quarter of the data rate of single-user space multiplex, but the system data rate is the same, because 4 users are using the resources.

The trade-off between space multiplex and space diversity was investigated with reference to system throughput (the total data rate in the cell) and the user data rates. High data rates for an individual user can be achieved with a high signal-to-interference ratio (SIR) using Single User Space Multiplex. Simulations showed that in an interference-limited system the areas with a high SIR are relatively small and the benefit in terms of system throughput is comparatively more modest in the case of space multiplex. However, single user space multiplex can be used for the transmission of very high data rates for isolated cells or for users in the vicinity of the base station. Space diversity, however, has more benefits than space multiplex for mobile systems which are generally interference-limited and have a low SIR, and overall allows for higher system throughput.

With beamforming, multiple users can be addressed simultaneously by the same resource (SDMA), or strong interference signals can be suppressed.

Hybrid forms of the different MIMO applications are likely to acquire great importance for LTE in practice. Thus, for example, beamforming can be used to constitute individual sectors and Space Multiplex or Space Diversity can then be used within the sector – depending on the quality of the radio channel and the distance of the user from the base station.

5 Mobile radio networks

LTE was used initially to accommodate the strong growth in data traffic. Meanwhile, the introduction of the speech service (VoIP) is expected shortly or has already been completed in some mobile radio networks (see Chapter 6).

Market penetration of LTE-capable user devices and net coverages, in Switzerland as in other countries, has already made considerable progress because of the approximate 80% penetration of smartphones. As a result, the traffic load is shifting increasingly from the 2G and 3G networks to the LTE networks.

In particular, the significance of GSM (2G) is reducing and the spectrum will be used by spectrally more efficient technology (bits per second and Hertz bandwidth) (see Figure 9 and 4.1).

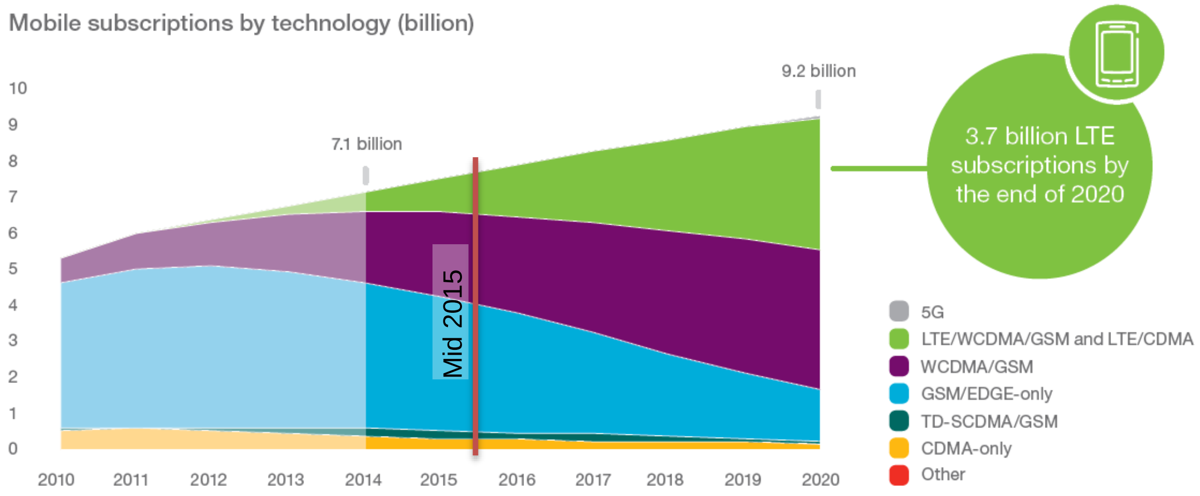


Figure 8: Evolution of subscriber connections according to technology
(Source: Ericsson Mobility Report, June 2015)

The switch from GSM/EDGE, which according to Figure 4 has an average spectral efficiency of 0.09 bit/s/Hz/cell, to HSPA Rel. 7 at 1.3 bit/s/Hz/cell or to LTE Rel. 8 at 1.8 bit/s/Hz/cell, means an average capacity increase by a factor of at least 10 or approximately 20 with the same assigned bandwidth. Generally, GSM/EDGE has been and will be replaced in the 900 MHz band by UMTS/HSPA+ and in the 1800 MHz band by LTE and LTE-A.

The importance of the "layering" as used in mobile radio networks, i.e. varying cell radii, is being further refined by LTE. After macrocells, which may extend up to several tens of kilometres in radius in a rural environment, the importance of smaller coverage cells such as microcells and picocells is increasing with the growing volume of traffic. In urban and suburban environments the cell radius, depending upon mobile radio traffic density, is sometimes less than 2 km.

Picocells have a range similar to that of a cordless telephone (DECT), some 60 metres indoors and 250 metres outdoors. The primary purpose of micro, pico and femto cells is offloading of the macrocell layers. The fastest possible feed and return of mobile radio traffic via DSL, coaxial and optical fibre networks (FTTx) and radio relay links into the core network relieve the macrocell network of traffic volume.

A significant proportion of the total traffic volume in mobile networks occurs in buildings (e.g. homes and offices), i.e. in the immediate vicinity of fixed-network connections. So-called indoor coverage systems and coverage systems in tunnels, stores and multi-storey car parks, etc. are already common today, but the vast majority of small cells do not yet support LTE. This is, however, only a question of time, because a paradigm shift is set to take place: Indoor-out coverage (from the inside out) must be provided by such femtocells and mobile radio traffic, in particular the enormous future volumes of data to be transferred, must be routed as closely as possible to the place of origin into the core/fixed network. Coverage of users in the vicinity of buildings is not a priority in this context. The current coverage strategy of outdoor-in coverage, i.e. coverage inside buildings provided from a base station outside, must be expanded. The goal is coverage of outdoor users by outdoor cells and indoor users by small indoor cells. Such a mobile radio network is a heterogeneous network. [11]

In the case of networks with a large number of base stations, such as occur lately in heterogeneous networks, signalling constitutes a major challenge. The LTE standard therefore already includes adaptations which concern signalling in particular.

The LTE standard includes functions for the self-organisation of the network (SON) as well as interference avoidance using Radio Resources Management (RRM) and Inter-Cell Interference Coordination (ICIC). These functions prevent interference between cells and simplify network planning. As a result it should be possible to further maximise data throughput whilst simultaneously reducing costs. [10]

6 Services

The list of services is short, as all services are provided using Internet Protocol (IP). Access network (LTE) and core network (EPC, EPS, SAE) have eliminated circuit-switching and voice services offered by the network operator are provided via "Managed VoIP"[9], e.g. VoLTE.

A voice communication service is not yet included in the 3GPP LTE standard (as of today). Consequently different proprietary solutions from network equipment providers exist.

One increasingly common solution is the industry standard "Voice over LTE" (VoLTE), which was drawn up by the GSM Association (GSMA). The GSMA is an association of mobile network operators and network equipment suppliers. The GSMA standardises the voice service and SMS, based on the IP Multimedia system (IMS). IMS is the operator's "Service Cloud" which for its part is a component of the service architecture (SAE). [8]

In Switzerland the first operator supported VoLTE from mid-2015. In May 2015 the top-end smartphone models supported VoLTE.

The 3GPP system differentiates between standardised traffic classes and quality of service (QoS). These are characterised, among other things, by:

- transmission delay
- bit/packet error rate (BER/PER)
- priority
- guaranteed minimum data rate (GBR)
- package delivery sequence

For example, the data packets of a VoIP service require above all a short delay in transmission and a guaranteed minimum bit rate, in order to ensure the quality of the voice service. The packet error rate is less important, unlike when downloading a file. Table 2 shows examples of requirements of various applications with regard to the QoS attributes. [9]

Application	Priority	Maximum delay	Packet error rate (PER)	Minimum guaranteed bitrate (GBR)
VoIP	2	100 ms	0.1 %	Yes, e.g. 172 kbps
Web browsing	8	300 ms	0.0001 %	No

Table 2: Examples of QoS attributes for different services

[9] Managed VoIP means that the operator guarantees speech quality by taking appropriate measures.

7 References

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