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UMTS factsheet

Universal Mobile Telecommunications System

Summary

Mobile radio data transmission was launched in 2002 with the construction of the UMTS mobile radio networks. Data rates of up to 2 Mbit/s became a reality. UMTS is a mobile radio standard of the third generation (3G) and the follow-on technology to GSM (Global System for Mobile Communications), which has become known as a second-generation (2G) system and which is used mainly for voice transmission. UMTS works with the WCDMA (Wideband Code Division Multiple Access) transmission technique with a channel bandwidth of 5 MHz.

The overwhelming proportion of data traffic on mobile networks is currently handled by UMTS/HSPA+ (Evolved High Speed Packet Access) technology. HSPA+ is a further development of UMTS and was introduced from 2010 onwards. Thanks to improved modulation techniques, the bundling of multiple channels, improved management of channel codes and multiple antennas (MIMO), the UMTS standard was able to deliver much more than was originally planned. The UMTS/HSPA+ currently allows, theoretically and under optimal propagation conditions, transmission rates of up to 21 Mbit/s per user with a single channel (5 MHz bandwidth). This can even be doubled with multiple antennas.

In the long run UMTS/HSPA+ will be replaced or supplemented by the more modern LTE (Long Term Evolution) system, initially in areas with a high population density. The two systems, LTE and UMTS/HSPA+, however, will continue to exist in parallel for some considerable time. Not least because UMTS/HSPA+ ensures very good coverage even in rural regions.

Contents

1 Introduction

In order to meet the requirements for higher data rates and higher spectrum efficiency, the basic conditions for a new mobile radio system, which was intended as a successor to GSM, were being developed as early as 1992 by the International Telecommunication Union. These minimum requirements had been published under the designation IMT-2000 (International Mobile Telecommunications of the year 2000). IMT 2000 systems are also commonly known as 3G systems, i.e. third-generation systems. UMTS is a member of this IMT 2000 family, as are the two systems originating in the USA, CDMA2000 and mobile WiMAX.

UMTS had initially been developed in Europe, but very soon some major non-European countries (the USA, China, Japan and Korea) had begun to show interest in this system and participated actively in its standardisation. Today, UMTS - like the other important mobile radio systems GSM/EDGE and LTE - is being supported and further developed by the worldwide standardisation organisation 3GPP (3rd Generation Partnership Project). The European standardisation organization ETSI is a partner of 3GPP.

Mobile radio data transmission was launched in 2002 with the commercial introduction of the UMTS mobile radio standard. Maximum data rates of 2 Mbit/s, typically 384 kbit/s per user, became possible as a result.

UMTS/HSPA+, a further development of UMTS, allows, theoretically and under optimal propagation conditions, transmission rates of up to 21 Mbit/s per user with a single channel (5 MHz bandwidth). UMTS/HSPA+ currently has by far the highest market penetration of all the 3G mobile radio technologies. Worldwide, some 26% of users were communicating via this technology in 2014. Ovum estimates that this market share will even increase over the next few years and is expected to attain a 42% share in the year 2020.

The figure below illustrates the development of user numbers for the most important mobile radio technologies:

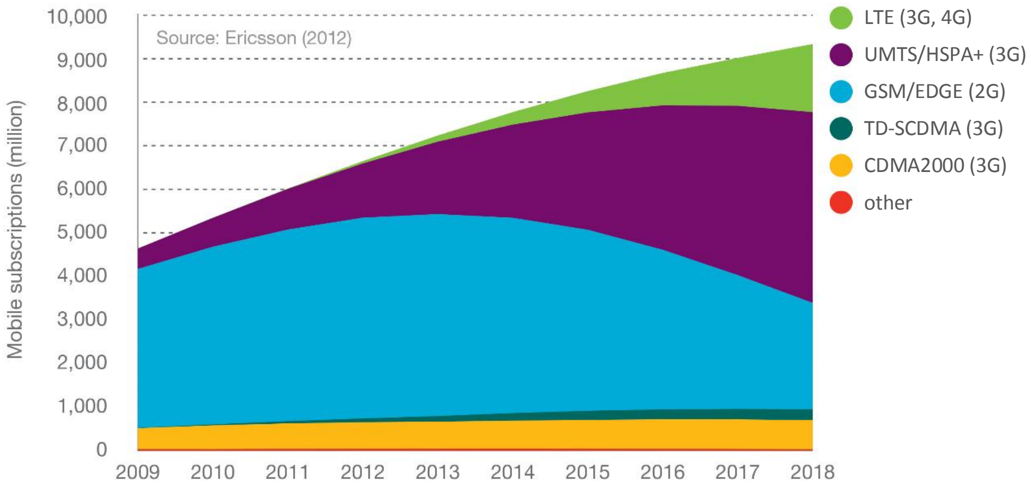

Figure 1: Development of user numbers for different mobile radio technologies

TD-SCDMA is the Chinese variant of UMTS and CDMA2000 is an American mobile radio system which has been implemented predominantly in North America, but also in parts of Asia and Africa.

UMTS/HSPA+ has been introduced in most countries throughout the world. Unfortunately, for historical reasons, different frequencies are used in different regions of the world. In Europe, UMTS/HSPA+ is operated almost exclusively in the 2.1 GHz and 900 MHz band (here still in parallel with GSM), but in North America it is operated in the 850 MHz and 1900 MHz band. Roaming is therefore not guaranteed in every case.

2 Technology

2.1 Air interface

The air interface enables wireless communication between the user equipment (mobile phone) and the base station. On this air interface, a brand new transmission technique, compared to GSM, is used for UMTS: WCDMA (Wideband Code Division Multiple Access). WCDMA is a technique in which all users on a network communicate on the same frequency. Separation of the individual channels is accomplished by means of a channel code, which is assigned to each user when the call is set up. The technique is shown schematically in the figure below [1]:

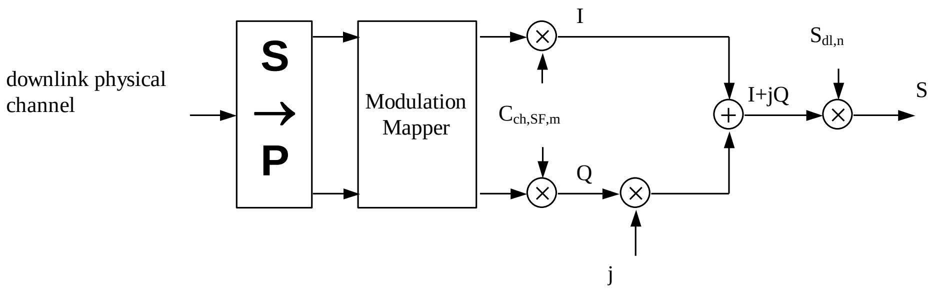

Figure 2: WCDMA processing on the downlink

The bits to be transmitted (downlink physical channel) for user *m* are converted from serial to parallel in the base station *n* (SP). From the bits, the modulation mapper generates the symbols corresponding to the chosen modulation technique (QPSK, 16QAM or 64QAM). The in-phase or quadrature components of the symbols are then multiplied (spread) by the channel code for the user *m* ($C_{CH, SF, m}$). The channel codes of all users within a cell are orthogonal in relation to each other and do not interfere with each other. The two spread signals I and Q are summed and then multiplied by the complex cell code of the cell *n* ($S_{dl, n}$). The resulting signal S is finally added in the base station to the signals for the other users in the cell and transmitted. The chip rate of the two spread codes is 3.84 Mchips/s. This chip rate determines the channel bandwidth. In the figure, *j* stands for the imaginary unit.

In the user's receiver equipment, this process is reversed in order to regenerate the desired bits.

This method fundamentally distinguishes UMTS from other radio systems (GSM, LTE, DECT, TETRA, etc.), in which the individual active users in a cell are separated from each other by different frequencies or time slots.

With WCDMA, it is possible to construct a comprehensive mobile radio network on a single 5 MHz channel (with GSM, approximately 9 to 12 channels are necessary, but these only have a bandwidth of 200 kHz). In each cell this channel can be re-used (reuse 1). The individual cells are distinguished from each other by an individual cell code in order to reduce interference between the cells.

A user who is at the periphery of the coverage area of several base stations can be served with the WCDMA technique by several base stations simultaneously. The individual signals are coherently combined in the user equipment with a relatively simple so-called rake receiver. This greatly improves coverage at the periphery of the cell. This capability, which is termed a soft handover, ensures very good coverage; in this case, however, at the expense of the code resources and transmitting power of the base stations involved. With this rake receiver, reflections which occur on the propagation path can also be optimally received.

In the case of UMTS the transmitting power is constantly and rapidly adapted to the propagation conditions (distance between user and base station, obstacles on the transmission channel, etc.), especially on the uplink (from the user to the base station) but also on the downlink (from the base station to the user). The transmitting power is always selected to be as high as necessary for adequate connection quality. UMTS user equipment therefore transmits with much lower power than is the case with GSM systems. With UMTS it is important to work with the minimum necessary transmitting powers; otherwise the capacity of the network is greatly reduced or in the worst case breaks down completely.

Two modes are specified for the UMTS air interface: FDD mode (Frequency Division Duplex) and TDD mode (Time Division Duplex). In FDD mode, two separate frequencies are used for a connection, i.e. one for the connection from the user to the base station (uplink) and one from the base station to the user (downlink).

In TDD mode, however, only one frequency is required for a connection. The uplink and downlink are on the same frequency, but in different time slots. No equipment has been developed by the industry for the UMTS TDD mode, and there has indeed been no demand from operators either. Apart from China, where a special variant of UMTS TDD is widespread, TDD mode is not used in UMTS. The frequencies, which were originally envisaged in Europe for UMTS TDD mode in the 2.1 GHz band, are now being assigned to a different use.

The maximum transmitting power of UMTS user equipment is 250 mW. In a real network, however, the actual transmitting powers fall well below this maximum value. Simulations by manufacturers and network operators have shown that the *average* transmitting power of UMTS user equipment in a rural environment is approximately 1.5 mW and in an urban environment is even lower [3]. The transmitting power of base stations depends on cell size, services provided, traffic and the distribution of users within the cell. For compatibility computations, an effective isotropic radiated power (EIRP) of approximately 320 W (55 dBm) per carrier frequency is used for the base stations in large cells [3].

Similarly to GSM, in each cell of a UMTS network, control channels are continuously emitted, regardless of the traffic in the cell. Typically, the transmitting power of these channels is approximately 20% of the total transmitting power of the base station.

The UMTS air interface has been constantly extended and supplemented in recent years. In 2006, HSDPA (High Speed Downlink Packet Access) was introduced. In this innovation, data rates of up to 14 Mbit/s are possible on the downlink, under ideal conditions. Then, in the following year, HSUPA (High Speed Uplink Packet Access) was implemented. With this, data rates of up to 5.76 Mbit/s are possible on the uplink. Both techniques, simply speaking, are based on optimised management of the channel codes in the network (several channel codes can now be assigned to each connection), and on the introduction of more efficient modulation techniques.

The overwhelming proportion of the data traffic on mobile networks is currently handled by the more advanced UMTS/HSPA+ (Evolved High Speed Packet Access) technology, which was introduced into networks from 2010 onwards. Thanks to improved modulation techniques, the bundling of multiple channels (Dual Carrier) and the introduction of multiple antennas (MIMO), the UMTS standard was able to deliver much more than was originally planned. UMTS/HSPA+ currently allows, theoretically and under optimal propagation conditions, transmission rates of up to 21 Mbit/s per user with a single channel (5 MHz bandwidth). For UMTS/HSPA+, the receivers in the user equipment are necessarily of more complex construction and must be equipped with a linear equaliser. The simple rake receivers which were originally used with UMTS are no longer sufficiently powerful. Therefore, soft handover at the periphery of the cell (see above) is no longer possible.

Key features of HSPA+ include rapid and flexible data load sharing and adaptation of the transmission signal to the channel quality by means of adaptive modulation and coding. The average spectrum efficiency (utilisation of radio frequencies in bits per second per Hertz and per cell) is some 8 times higher with UMTS/HSPA+ than with GSM/EDGE.

2.2 MIMO

Multiple Input Multiple Output (MIMO) has already been in use for some time in mobile radio. As the name suggests, in this case multiple antennas are used at the base station and at the user equipment. Different data streams can be transferred on the same frequency and for the same call via the individual antennas. At the reception side, the signals can be decoded again with the aid of complicated algorithms. When the number of antennas is doubled on both sides of a radio link, the data rate can therefore be doubled, theoretically, without additional frequency resources and without additional transmitting power. As a result of the extension of UMTS by MIMO technology, there is another dimension, the spatial dimension, in addition to frequency and time. In this context, the term *space multiplex* is also used.

Alternatively, MIMO techniques can be used to increase the signal-to-noise ratio, and hence the quality of radio communication, rather than increasing the data rate. By sending the same coded transmission via several antennas, the quality of the signal at the periphery of the cell - for the same total transmitting power of all antennas together - can be improved substantially (diversity gain), but without an increase in the data rate. In this way the radius of the cell can be increased.

With UMTS/HSPA+, MIMO has been supported and implemented since Release 7 (2008). The simulation of a mobile radio outfitter has shown that that in a UMTS/HSPA+ mobile radio network with a 2x2 MIMO (two transmitting and two receiving antennas) the average value of the data rates of individual users can be increased by 20%, compared to a conventional 1x1 system. For individual well-positioned users in the cell, in radio technology terms, the capacity increase can even exceed 50% [4].

2.3 Multi-Cell (Multi-Carrier)

Another feature of UMTS/HSPA+ is the possibility of bundling several channels for a single connection. The data rate can accordingly be increased by this enlargement of the bandwidth. With HSPA+ Release 10, up to 4 channels of 5 MHz respectively can be combined into a single connection with a bandwidth of 20 MHz. Depending on number of bundled channels, one speaks of Dual-Cell, Triple-Cell or Quad-Cell. The channels must be located directly adjacent to each other.

2.4 Data rates

The maximum data rates of UMTS/HSPA+ are constantly being increased from one release of the standard to the next. This process is not yet complete.

By means of

- new modulation techniques,
- assignment of several channel codes for a specific user connection,
- bundling of several channels for one connection (see section 2.3)
- and the use of MIMO in the base station and user equipment (see section 2.2)

and under ideal propagation conditions, data rates of up to 168 Mbit/s per user have become possible with UMTS/HSPA+. As will be shown later, these maximum data rates are only theoretically attainable. In a real network, all active users have to share this capacity. Also, propagation conditions are never ideal in real networks and data rates are additionally greatly reduced as a result.

In the illustration below, this development of the theoretically possible maximum data rate is represented graphically as a function of the Release (R) of the standard:

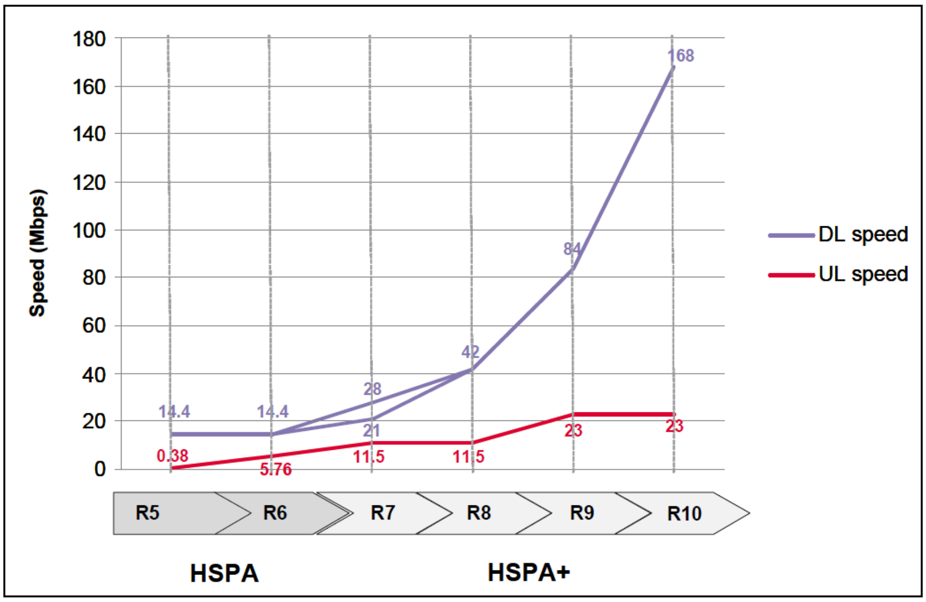

Figure 3: **Development of maximum data rates on the UL and DL**

The number of the releases approximates to the year of the publication of the corresponding standard. Equipment complying with Release 7 (R7), for example, was introduced commercially in the year 2008.

The equipment category determines the maximum data rate which an item of user equipment can receive. In Release 10 (R10) of the standard, 32 equipment categories of ascending complexity are defined. A list of functionalities (MIMO, multi-carrier, modulation, number of parallel channel codes) which the corresponding equipment supports, as well as the theoretical maximum data rates, is shown in the following table [2].

Table 1: Maximum data rates on the downlink for different equipment categories (R10)

equipment category	nbr. of codes	modulation scheme	*# carriers (bandwidth)*	MIMO	max. bit rate [Mbit/s]
1	5	QPSK, 16QAM	1 (5 MHz)	no MIMO	1.2
2	5				1.2
3	5				1.8
4	5				1.8
5	5				3.6
6	5				3.6
7	10				7.2
8	10				7.2
9	15				10.1
10	15				14.0
11	5	QPSK			0.9
12	5				1.8
13	15	QPSK, 16QAM, 64QAM			17.6
14	15				21.1
15	15	QPSK, 16QAM		MIMO	23.4
16	15				28.0
17	15	Cat. 13 & Cat. 15			
18	15	Cat. 14 & Cat. 16			
19	15	QPSK, 16QAM, 64QAM			35.3
20	15				42.2
21	15	QPSK, 16QAM	2 (10 MHz)	no MIMO	23.4
22	15				28.0
23	15	QPSK, 16QAM, 64QAM			35.3
24	15				42.2
25	15	QPSK, 16QAM		MIMO	46.7
26	15				55.9
27	15	QPSK, 16QAM, 64QAM			70.6
28	15				84.4
29	15		3 (15 MHz)	no MIMO	63.3
30	15			MIMO	126.6
31	15		4 (20 MHz)	no MIMO	84.4
32	15			MIMO	168.8

Equipment category 10, for example, allows a bit rate of 14 Mbit/s in the 5 MHz bandwidth with 16QAM modulation and 15 parallel codes. This indicates that the transferred data is not coded (protected) on the radio channel and susceptibility to interference is therefore substantial[1]. Typical user equipment without MIMO and without the multi-carrier capability belongs to equipment category 6 (3.6 Mbit/s) or equipment category 8 (7.2 Mbit/s). For users at the periphery of the cell in particular, propagation losses and interference from neighbouring cells means that the actual data rates are far below the maximum values shown in the above table.

From the table it is also evident that for specific equipment categories either the MIMO option or the Multi-Cell option exists, but not both options at the same time. For example the data rate of 42.2 Mbit/s can be achieved either with Dual-Cell (10 MHz bandwidth, equipment category 24) or with MIMO and only one channel (5 MHz bandwidth, equipment category 20). The operator is free to decide which technology (MIMO vs. Multi Cell) it wishes to use to extend the capacity in its network. For Dual-Cell,

[1] 16QAM in the bandwidth of 3.84 MHz (chip rate) with 15 of 16 channel codes without channel coding results in a theoretical bit rate of: 3.84 MHz x 4/bit/s/Hz x 15/16 = 14.4 Mbit/s

however, two carrier frequencies are then required. In any event, appropriate user equipment is a condition for an increase in the data rate.

In practice, under actual propagation conditions, it is difficult to achieve the theoretical maximum data rates in Table 2. In the following table, the typical average data rates of modern mobile radio technologies are compared with the maximum data rates:

Table 2: Maximum data rates and average data rates for different mobile radio technologies

technology	bandwidth [MHz]	max. bitrate [Mbit/s]		typical bitrate [Mbit/s]		MIMO
		Downlink	Uplink	Downlink	Uplink	
HSPA+ (3.75G)	5	42.2	11.5	7	2	DL: 2x2, UL: 1x2
LTE (3.9G)	10	86	43	18	7	DL: 2x2, UL: 1x2
LTE-A (4G)	10	150	68	24	12	DL: 4x4, UL: 2x2

The typical (average) data rate for a user in a real environment is 5 to 6 times lower than the theoretical maximum value. It should be noted that for HSPA+ in the above table the transmission bandwidth of 5 MHz was used as a basis, but 10 MHz was used for LTE.

3 Networks

The network architecture of UMTS consists of the UTRAN access network (UMTS Terrestrial radio Access Network) and the core network CN. The illustration below shows in greatly simplified form the UMTS network architecture with the corresponding interfaces:

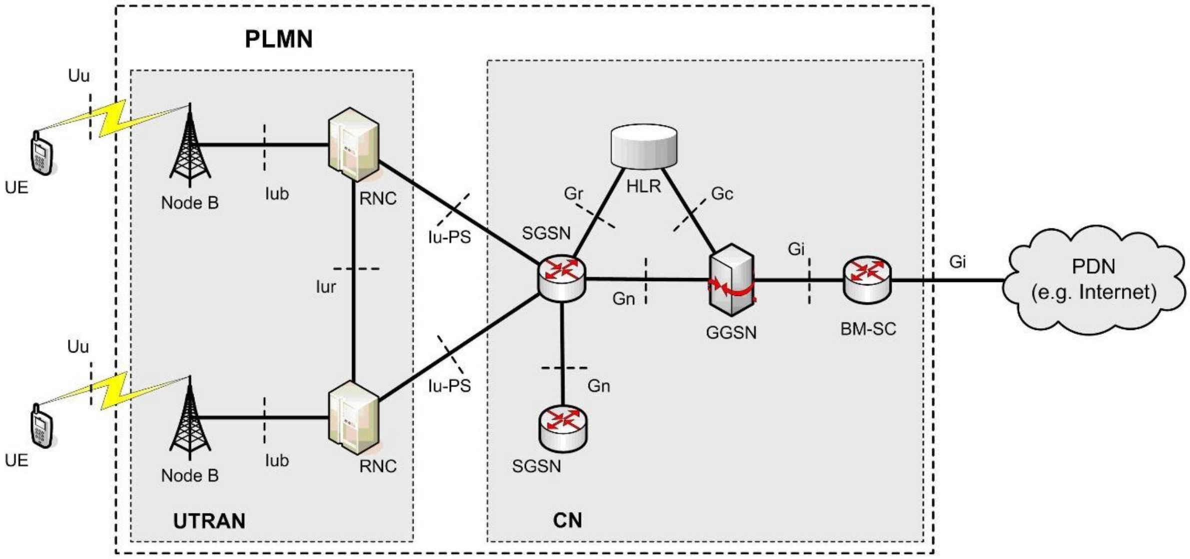

Figure 4: UMTS network architecture

The access network consists of the base stations, termed Node B in UMTS and the RNC (Radio Network Controller). The main functions of the RNC are routing of calls between Node B, monitoring of Node B and assignment of resources for the air interface. In the UTRAN the RNCs are networked (Iur interface). Among other things a so-called soft handover is therefore possible. This means that several base stations can supply a particular item of user equipment (UE) and thereby substantially improve coverage at the periphery of the cell.

The packet-based data traffic is handled in the core network by the SGSN (Serving GPRS Support Node). The SGSN forwards IP packets, which are intended for the user equipment in the SGSN coverage area or which are sent by such equipment. The tasks of an SGSN include routing and transfer of packets into or out of the SGSN's coverage area. The mode operates all user equipment which is in the SGSN's coverage area. In addition, the SGSN performs coding and authentication, session and mobility management, as well as handling the connection to the HLR (Home Location Register) and the GGSN (gateway GPRS Support Node).

The HLR is the central user database in the mobile radio network. It stores the user and subscriber information. The information stored in the HLR is used for mobility management and user identification and hence for secure access to the mobile radio network. The services to which the user has access and their location data are also recorded.

Finally, routing into the internet is performed by the GGSN. It provides all gateway functions necessary for handling the data traffic. These include the provision of the interface to external IP networks and the internet. From the viewpoint of an external IP network, the GGSN functions as a router for IP addresses of all users served by the UMTS network.

4 Services

The performance of UMTS has made possible a series of new services. In addition to the voice telephone service with good speech quality, these include in particular multimedia data services based on the Internet Protocol.

In the case of the first networks, the UMTS core networks supported circuit-switched (CS) transmission services for the voice telephony service and packet switched (PS) transmission services for data traffic. The voice telephony service was then fed into the core network of the then dominant GSM systems, which was optimised for voice services and connected to the traditional fixed telephone network (ISDN). Today transmission in the core network is based very largely on the packet-switched Internet Protocol (IP). Voice services are also carried via IP (VoIP). Thus there is a uniform packet-switched core network for all services (Full IP).

Different applications on the network have different performance and quality requirements. Quality requirements include, for example, the permissible delays (a critical factor especially for voice transmission), fluctuations in these delay times, error rates and guaranteed data rates. The following four QoS classes have been defined for UMTS for applications with qualitatively similar requirements:

- Conversational: VoIP, video conference, audio conference. . .
- Streaming: Broadcast audio and video, audio and video clips. . .
- Interactive: Surfing the internet, chat, games. . .
- Background: E-mail, data downloads and uploads, telemetry. . .

5 UMTS licences in Switzerland

After the holding of an auction at the end of 2000, the Federal Communications Commission (ComCom) awarded four UMTS licences. Licence number 1 went to Swisscom AG for the sum of CHF 50 million, licence number 2 went to Sunrise for the sum of CHF 50 million, licence number 3 went to Orange Communications SA (now Salt) for the sum of CHF 55 million and licence number 4 was acquired by 3G mobile AG for the sum of CHF 50 million.

In the 2.1 GHz band (the UMTS core band), each operator received 2x15 MHz FDD frequencies and 5 MHz TDD frequencies; altogether, therefore, each operator was assigned 35 MHz from the 2.1 GHz band.

In their licence decision, the operators were subject to the condition that by the end of 2004 at the latest they had to provide 50% of the Swiss population with UMTS services. Operators of UMTS networks which already possess a GSM network also had an obligation to provide the new UMTS operator without a GSM network with national roaming. Thus a new operator had the possibility of achieving good coverage from the outset, by means of a roaming agreement with an established GSM network operator.

The licences were awarded for a term of 15 years.

The coverage conditions involving 50% population coverage were achieved as of 31 December 2004 by Orange, Sunrise and Swisscom. Only 3GMobile as the fourth UMTS licensee had not constructed a corresponding infrastructure by the deadline. Subsequently ComCom, by its decision of 12 April 2006, revoked the licence from 3G Mobile. The revocation of the licence was confirmed by the decision of the Federal Court on 26 October 2006.

Orange, Sunrise and Swisscom were assigned mobile radio frequencies in the framework of another auction, which was held at the beginning of 2012. The award concerned on the one hand the frequencies which were free at the time and those expected to become free in the foreseeable future and on the other hand all the frequencies which had been awarded to the bidders in the past. The total assigned bandwidth after this auction was as follows:

Table 3: Assigned bandwidths for mobile radio in Switzerland

Frequenzband	Salt (Orange)	Sunrise	Swisscom
800 MHz	20 MHz	20 MHz	20 MHz
900 MHz	10 MHz	30 MHz	30 MHz
1800 MHz	50 MHz	40 MHz	60 MHz
2.1 GHz FDD	40 MHz	20 MHz	60 MHz
2.1 GHz TDD	0	0	0
2.6 GHz FDD	40 MHz	50 MHz	40 MHz
2.6 GHz TDD	0	0	45 MHz

The new assignment of the UMTS core band at 2.1 GHZ is effective from the end of 2017.

The newly awarded licences will run until the end of 2028. They are configured to be technology-neutral. That means that the operators can use UMTS in all the frequency ranges assigned to them, if the general technical conditions so allow.

According to one operator's information, over 99% per cent of the Swiss population can already (2014) surf with UMTS/HSPA+ on their mobiles with a data rate of 7.2 Mbit/s (at selected locations even 42 Mbit/s).

Abbreviations

CDMA	Code Division Multiple Access
CS	Circuit Switched
DL	Downlink
EDGE	Enhanced Data Rates for GSM Evolution
EIRP	Equivalent Isotropically Radiated Power
ETSI	European Telecommunications Standards Institute
FDD	Frequency Division Duplex
GGSN	Gateway GPRS Support Node
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
HLR	Home Location Register
HSDPA	High Speed Downlink Packet Access
HSPA+	Evolved High Speed Packet Access
HSUPA	High speed Uplink Packet Access
IMT-2000	International Mobile Telecommunications of the year 2000
IP	Internet Protocol
ITU	International Telecommunication Union
LTE	Long Term Evolution
MIMO	Multiple Input Multiple Output (multiple antenna)
PDN	Packet Data Network
PLMN	Public Land Mobile Network (mobile radio network)
PS	Packet Switched
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RNC	Radio Network Controller
SGSN	Serving GPRS Support Node
TDD	Time Division Duplex
TD-SCDMA	Time Division Synchronous Code Division Multiple Access
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunications System
UTRAN	UMTS Terrestrial Access Network
VoIP	Voice over IP
WCDMA	Wideband Code Division Multiple Access

Literature

[1] 3GPP TS 25.213: Spreading and modulation (FDD) (Release 10).

[2] 3GPP TS 25.306: UE Radio Access capabilities (Release 10).

[3] Report ITU-R M.2039-2: Characteristics of terrestrial IMT-2000 systems for frequency sharing/interference analyses (11/2010).

[4] GSMA: MIMO in HSPA: the Real-World Impact, 2010.