1

Introduction

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1.1 Mobile Voice Subscriber Growth

The number of mobile subscribers has increased tremendously during the last decade: the first billion landmark was exceeded in 2002, the second billion in 2005, the third billion in 2007 and the fourth billion by the end of 2008. More than 1 million new subscribers per day have been added globally, that is more than ten subscribers on average every second. This growth is illustrated in Figure 1.1. Mobile phone penetration worldwide is approaching

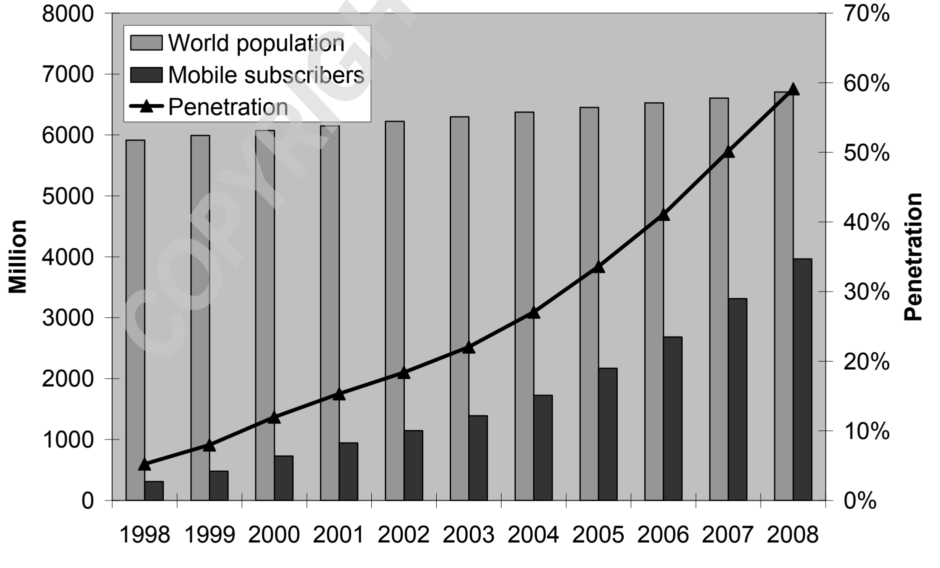

Figure 1.1 Growth of mobile subscribers

LTE for UMTS – OFDMA and SC-FDMA Based Radio Access. Edited by Harri Holma and Antti Toskala.

60%[1]. Voice communication has become mobile in a massive way. The mobile is the preferred method for voice communication, with mobile networks covering over 90% of the world's population. This voice growth has been fuelled by low cost mobile phones and efficient network coverage and capacity, which is enabled by standardized solutions and by an open ecosystem leading to the economies of scale. Mobile voice is not the privilege of the rich but also brings value for users on low incomes – because of the benefits of being connected, low income users spend a larger part of their income on mobile communications.

1.2 Mobile Data Usage Growth

The second generation mobile networks – like Global System for Mobile Communications (GSM) – were originally designed for carrying voice traffic while the data capability was added later. Data usage has increased but the traffic volume in second generation networks is clearly dominated by voice traffic. The introduction of third generation networks with High Speed Downlink Packet Access (HSDPA) has boosted data usage considerably. Example operator statistics for 12 months are shown in Figure 1.2 where the HSDPA downlink data volumes are several terabytes per day, which correspond to beyond 1 Gbps busy hour network level throughput. Such fast data growth shows that the end users find value in the wireless broadband access.

Data traffic volume has in many cases already exceeded voice traffic volume when voice traffic is converted into terabytes by assuming a voice data rate of 12 kbps. A typical case is illustrated in Figure 1.3. HSDPA data growth is advanced by high speed radio capability, flat rate pricing schemes and simple device installation. In short, the introduction of HSDPA has changed mobile networks from voice dominated to packet data dominated networks.

Data usage is advanced by a number of bandwidth hungry laptop applications including internet and intranet access, file sharing, streaming services to distribute video content and mobile

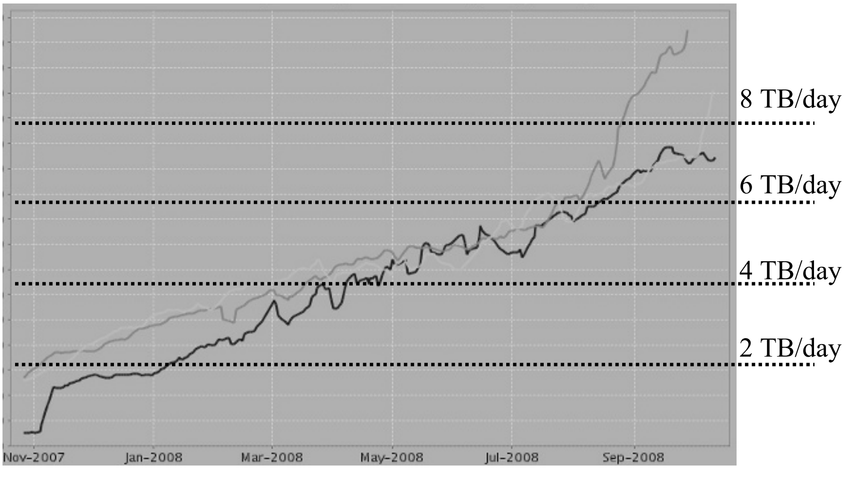

Figure 1.2 Growth of HSDPA data traffic

1 The actual user penetration can be different since some users have multiple subscriptions and some subscriptions are shared by multiple users.

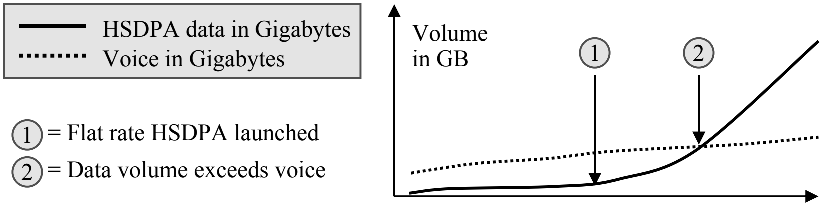

Figure 1.3 HSDPA data volume exceeds voice volume

TV and interactive gaming. In addition, service bundles of video, data and voice – known also as triple play – are entering the mobile market, also replacing the traditional fixed line voice and broadband data services with mobile services both at home and in the office.

A typical voice subscriber uses 300 minutes per month, which is equal to approximately 30 megabyte of data with a voice data rate of 12.2 kbps. A broadband data user can easily consume more than 1000 megabyte (1 gigabyte) of data. Heavy broadband data usage takes 10–100× more capacity than voice usage, which sets high requirements for the capacity and efficiency of network data.

It is expected that by 2015, 5 billion people will be connected to the internet. Broadband internet connections will be available practically anywhere in the world. Already today, the existing wireline installations can reach approximately 1 billion households and the mobile networks connect over 3 billion subscribers. These installations need to evolve into broadband internet access. Further extensive use of wireless access as well as new wireline installations with enhanced capabilities are required to offer true broadband connectivity to the 5 billion customers.

1.3 Wireline Technologies Evolution

Although wide area wireless networks have experienced a fast evolution of data rates, wireline networks still provide the highest data rates. The evolution of the peak user data rate both in wireless and wireline networks is illustrated in Figure 1.4. Interestingly, the shape of the evolution curve is similar in both domains with a relative difference of approximately 30 times. An application of Moore's law predicts that data rates double every 18 months. Currently, copper based wireline solutions with Very High Data Rate Digital Subscriber Line (VDSL2) can offer bit rates of tens of Mbps and the passive optical fibre based solution gives rates in excess of 100 Mbps. Both copper and fibre based solutions will have further data rate evolution in the near future, increasing the data rate offerings to the Gbps range.

Wireless networks must make data rates higher in order to match the user experience provided by wireline networks. When customers are used to wireline performance, they expect the wireless network to offer comparable performance. The applications designed for wireline networks advance the evolution of the wireless data rates.

Wireless technologies, on the other hand, have the huge benefit of being capable of offering personal broadband access independently of user location – in other words, mobility, for nomadic or full mobile use cases. A wireless solution can also provide low cost broadband coverage compared to new wireline installations if there is no existing wireline infrastructure. Therefore, wireless broadband access is an attractive option, especially in new growth markets in urban areas as well as in rural areas in other markets.

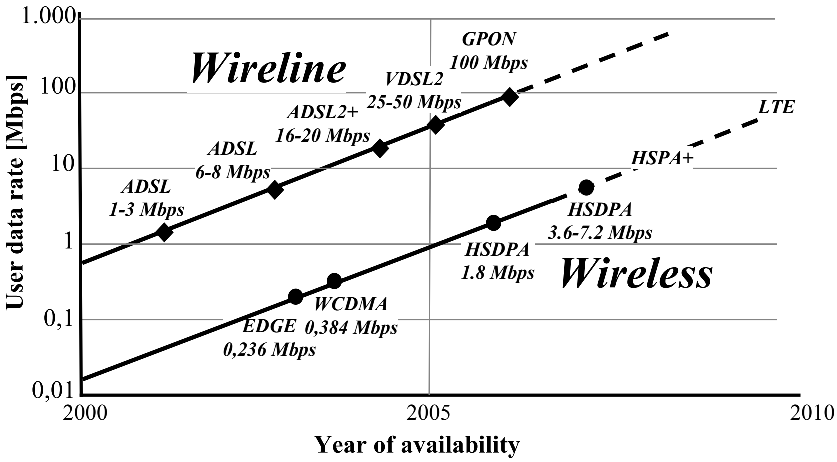

Figure 1.4 Evolution of wireless and wireline user data rates [Broadband Access for All - A Brief Technology Guide, Nokia Siemens Networks white paper (2007)]. GPON = Gigabit Passive Optical Network; VDSL = Very High Data Rate Subscriber Line; ADSL = Asymmetric Digital Subscriber Line

1.4 Motivation and Targets for LTE

The work towards 3rd Generation Partnership Project (3GPP) Long Term Evolution (LTE) started in 2004 with the definition of the targets. Even though HSDPA was not yet deployed at that time, it became evident that work for the next radio system should be started. It takes more than 5 years from setting the system targets to commercial deployment using interoperable standards. Therefore, system standardization must be started early enough to be ready by the time the need is there. A few driving forces can be identified advancing LTE development: wireline capability evolution, the need for additional wireless capacity, the need for lower cost wireless data delivery and the competition of other wireless technologies. As wireline technology keeps improving, a similar evolution is required in the wireless domain to make sure that the applications also work fluently in the wireless domain. There are also other wireless technologies – including IEEE 802.16 – which promise high data capabilities. 3GPP technologies must match and exceed the competition. More capacity is a clear requirement for taking maximum advantage of the available spectrum and base station sites. These reasons are summarized in Figure 1.5.

LTE must be able to deliver superior performance compared to existing 3GPP networks based on High Speed Packet Access (HSPA) technology. The performance targets in 3GPP are defined relative to HSPA in Release 6. The peak user throughput should be minimum 100 Mbps in downlink and 50 Mbps in uplink, which is ten times more than HSPA Release 6. Also the latency must be reduced in order to improve the end user performance. The terminal power consumption must be minimized to enable more usage of the multimedia applications without recharging the battery. The main performance targets are shown in Figure 1.6 and are listed below:

- spectral efficiency two to four times more than with HSPA Release 6;
- peak rates exceed 100 Mbps in downlink and 50 Mbps in uplink;

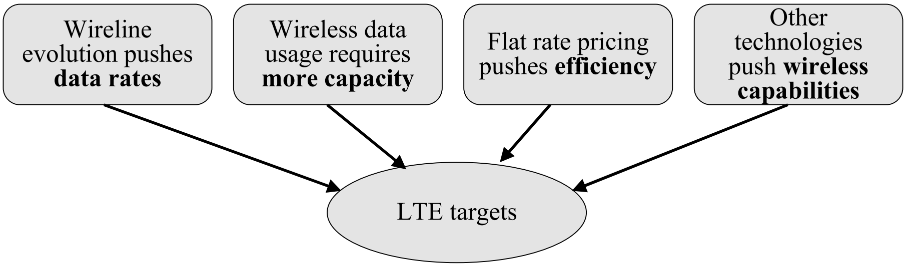

Figure 1.5 Driving forces for LTE development

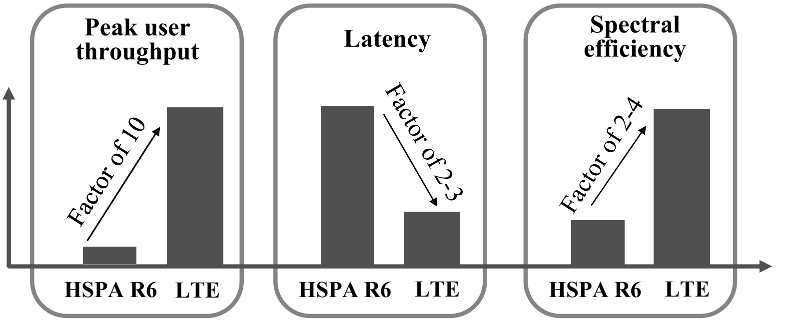

Figure 1.6 Main LTE performance targets

- enables round trip time <10 ms;
- packet switched optimized;
- high level of mobility and security;
- optimized terminal power efficiency;
- frequency flexibility with from below 1.5 MHz up to 20 MHz allocations.

1.5 Overview of LTE

The multiple access scheme in LTE downlink uses Orthogonal Frequency Division Multiple Access (OFDMA) and uplink uses Single Carrier Frequency Division Multiple Access (SC-FDMA). These multiple access solutions provide orthogonality between the users, reducing the interference and improving the network capacity. The resource allocation in the frequency domain takes place with a resolution of 180 kHz resource blocks both in uplink and in downlink. The frequency dimension in the packet scheduling is one reason for the high LTE capacity. The uplink user specific allocation is continuous to enable single carrier transmission while the downlink can use resource blocks freely from different parts of the spectrum. The uplink single carrier solution is also designed to allow efficient terminal power amplifier design, which is relevant for the terminal battery life. The LTE solution enables spectrum flexibility where the transmission bandwidth can be selected between 1.4 MHz and 20 MHz depending on the available spectrum. The 20 MHz bandwidth can provide up to 150 Mbps downlink user data rate with 2×2 MIMO, and 300 Mbps with 4×4 MIMO. The uplink peak data rate is 75 Mbps. The multiple access schemes are illustrated in Figure 1.7.

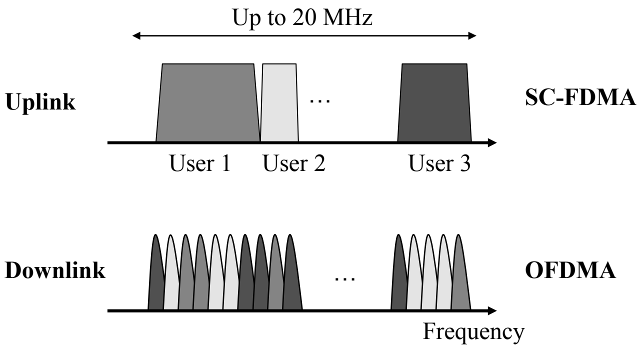

Figure 1.7 LTE multiple access schemes

The high network capacity also requires an efficient network architecture in addition to the advanced radio features. The target in 3GPP Release 8 is to improve the network scalability for traffic increase and to minimize the end-to-end latency by reducing the number of network elements. All radio protocols, mobility management, header compression and all packet retransmissions are located in the base stations called eNodeB. eNodeB includes all those algorithms that are located in Radio Network Controller (RNC) in 3GPP Release 6 architecture. Also the core network is streamlined by separating the user and the control planes. The Mobility Management Entity (MME) is just the control plane element while the user plane bypasses MME directly to System Architecture Evolution (SAE) Gateway (GW). The architecture evolution is illustrated in Figure 1.8. This Release 8 core network is also often referred to as Evolved Packet Core (EPC) while for the whole system the term Evolved Packet System (EPS) can also be used.

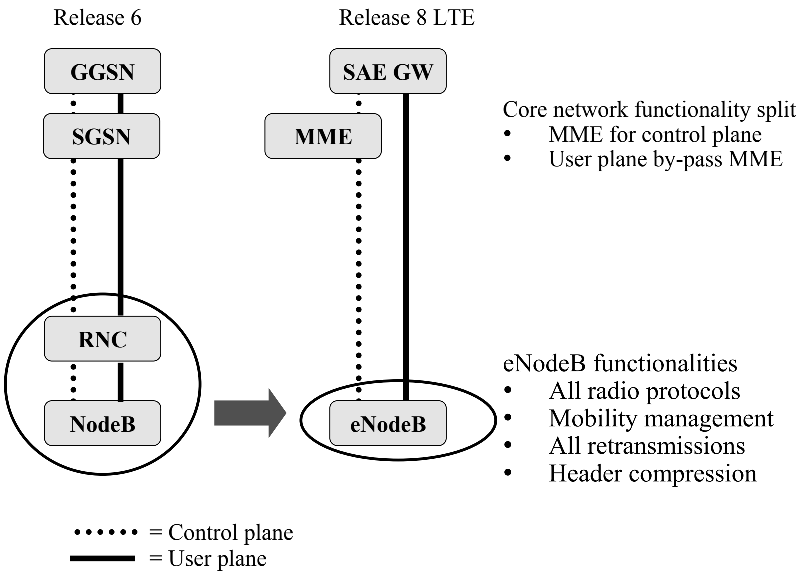

Figure 1.8 LTE network architecture

1.6 3GPP Family of Technologies

3GPP technologies – GSM/EDGE and Wideband Code Division Multiple Access (WCDMA)/ HSPA – are currently serving nearly 90% of the global mobile subscribers. The market share development of 3GPP technologies is illustrated in Figure 1.9. A number of major Code Division Multiple Access (CDMA) operators have already turned or are soon turning to GSM/WCDMA for voice evolution and to HSPA/LTE for data evolution to get access to the benefits of the large and open 3GPP ecosystem and economics of scale for low cost mobile devices. The number of subscribers using 3GPP based technologies is currently more than 3.5 billion. The 3GPP LTE will be built on this large base of 3GPP technologies.

The time schedule of 3GPP specifications and the commercial deployments is illustrated in Figure 1.10. Enhanced Data rates for GSM Evolution (EDGE) was defined in 3GPP in 1997 and WCDMA at the end of 1999. Both systems had their first commercial deployments during

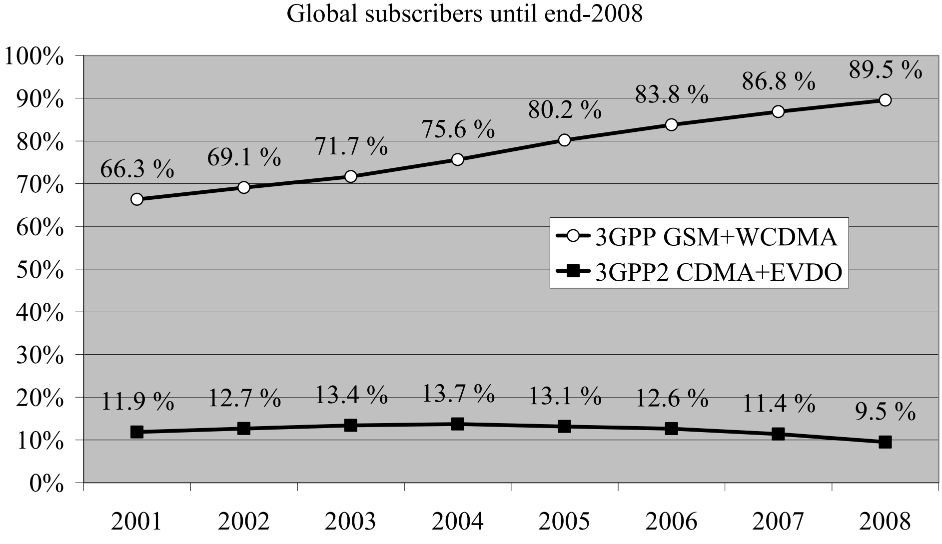

Figure 1.9 Global market share of 3GPP and 3GPP2 technologies. EVDO, evolution data only

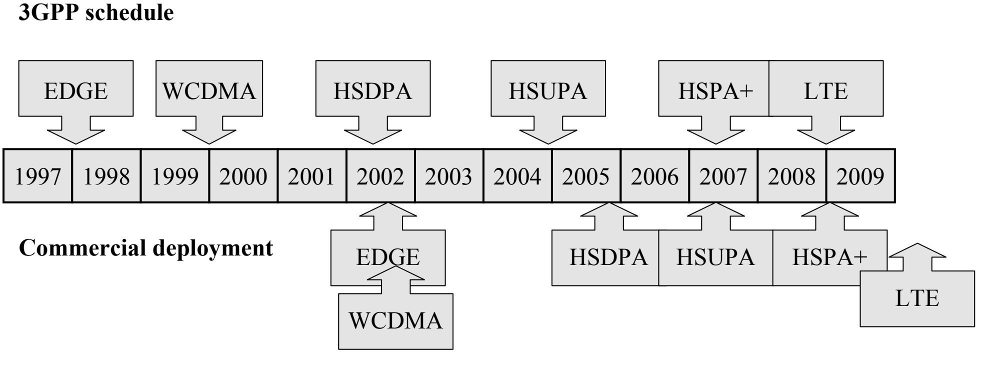

Figure 1.10 Schedule of 3GPP standard and their commercial deployments

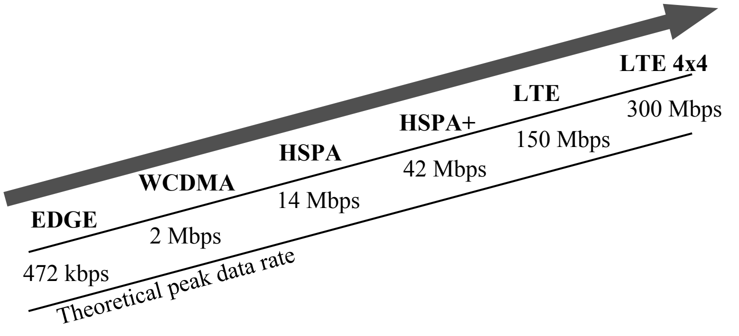

Figure 1.11 Peak data rate evolution of 3GPP technologies

2002. The HSDPA and High Speed Uplink Packet Access (HSUPA) standards were completed in March 2002 and December 2004, and the commercial deployments followed in 2005 and 2007. The first phase of HSPA evolution, also called HSPA+, was completed in June 2007 and the deployments start during 2009. The LTE standard was approved at the end of 2007, the backwards compatibility is expected to start in March 2009 and commercial deployments are expected in 2010.

The new generation of technologies pushes data rates higher. The evolution of the peak user data rates is illustrated in Figure 1.11. The first WCDMA deployments in 2002 offered 384 kbps, current HSDPA networks 7.2–14.4 Mbps, HSPA evolution 21–42 Mbps and LTE 2010 150 Mbps, that is a more than 300 times higher data rate over 8 years.

The 3GPP technologies are designed for smooth inter-working and coexistence. The LTE will support bi-directional handovers between LTE and GSM and between LTE and UMTS. GSM, UMTS and LTE can share a number of network elements including core network elements. It is also expected that some of the 3G network elements can be upgraded to support LTE and there will be single network platforms supporting both HSPA and LTE. The subscriber management and Subscriber Identity Module (SIM) based authentication will be used also in LTE; however, in LTE the system access requires the more modern and more secure Universal SIM (USIM) instead of the older 2G originated SIM card.

1.7 Wireless Spectrum

The LTE frequency bands in 3GPP specifications are shown in Figure 1.12 for paired bands and in Figure 1.13 for unpaired bands. There are 17 paired bands and 8 unpaired bands defined currently and more bands will be added during the standardization process. Some bands are currently used by other technologies and LTE can coexist with the legacy technologies. Similarly, in Europe and in Asia, WCDMA was initially deployed in the new 2100 MHz band while the refarming to the existing 900 MHz started during 2007. LTE will likely start by using the new 2600 MHz band and refarming to 900 and 1800 MHz bands. In the best case in Europe there is in total a 565 MHz spectrum available for the mobile operators when including 900 MHz, 1800 MHz, 2100 MHz Frequency Division Duplex (FDD) and Time Division Duplex (TDD) bands and the new 2600 MHz allocation all together.

Operating band	3GPP name	Total spectrum	Uplink [MHz]	Downlink [MHz]
Band 1	2100	2x60 MHz	1920-1980	2110-2170
Band 2	1900	2x60 MHz	1850-1910	1930-1990
Band 3	1800	2x75 MHz	1710-1785	1805-1880
Band 4	1700/2100	2x45 MHz	1710-1755	2110-2155
Band 5	850	2x25 MHz	824-849	869-894
Band 6	800	2x10 MHz	830-840	875-885
Band 7	2600	2x70 MHz	2500-2570	2620-2690
Band 8	900	2x35 MHz	880-915	925-960
Band 9	1700	2x35 MHz	1750-1785	1845-1880
Band 10	1700/2100	2x60 MHz	1710-1770	2110-2170
Band 11	1500	2x25 MHz	1427.9-1452.9	1475.9-1500.9
Band 12	US700	2x18 MHz	698-716	728-746
Band 13	US700	2x10 MHz	777-787	746-756
Band 14	US700	2x10 MHz	788-798	758-768
Band 17	US700	2x10 MHz	704-716	734-746
Band 18	Japan800	2x30 MHz	815-830	860-875
Band 19	Japan800	2x30 MHz	830-845	875-890

Figure 1.12 Frequency bands for paired bands in 3GPP specifications

Operating band	3GPP name	Total spectrum	Uplink and downlink [MHz]
Band 33	UMTS TDD1	1x20 MHz	1900-1920
Band 34	UMTS TDD2	1x15 MHz	2010-2025
Band 35	US1900 UL	1x60 MHz	1850-1910
Band 36	US1900 DL	1x60 MHz	1930-1990
Band 37	US1900	1x20 MHz	1910-1930
Band 38	2600	1x50 MHz	2570-2620
Band 39	UMTS TDD	1x40 MHz	1880-1920
Band 40	2300	1x50 MHz	2300-2400

Figure 1.13 Frequency bands for unpaired bands in 3GPP specifications

In the USA the WCDMA networks have been refarmed to 850 and 1900 MHz. The new frequencies at 1700/2100 are also used for 3G deployment. LTE will be deployed using 700 and 1700/2100 bands, and later refarmed to the existing bands.

In Japan the LTE deployments start using the 2100 band followed later by 800, 1500 and 1700 bands.

Flexible bandwidth is desirable to take advantage of the diverse spectrum assets: refarming typically requires a narrowband option below 5 MHz, while the new spectrum allocations could take benefit of a wideband option up to 20 MHz and higher data rates. It is also evident that both FDD and TDD modes are required to take full benefit of the available paired and unpaired spectrum. These requirements are taken into account in the LTE system specification.

1.8 New Spectrum Identified by WRC-07

The ITU-R World Radiocommunication Conference (WRC-07) worked in October and November 2007 to identify the new spectrum for International Mobile Telecommunications (IMT). The following bands were identified for IMT and are illustrated in Figure 1.14. The target was to identify both low bands for coverage and high bands for capacity.

The main additional coverage band will be in UHF frequencies 470–806/862 MHz that are currently used for terrestrial TV broadcasting. The sub-band 790–862 MHz was identified in Europe and Asia-Pacific. The availability of the band depends on the national time schedules of the analogue to digital TV switchover and it can become widely available within the 2012 to 2015 timeframe. The band allows, for example, three operators each running 10 MHz LTE FDD.

The sub-band 698–806 MHz was identified for IMT in the Americas. In the USA, part of the band has already been auctioned.

The main capacity band will be in 3.4–4.2 GHz (C-band). Total 200 MHz in the sub-band 3.4–3.8 GHz was identified for IMT in Europe and in Asia-Pacific. This spectrum can facilitate the deployment of a larger bandwidth of IMT-Advanced to provide the highest bit rates and capacities.

Additionally, the band 2.3–2.4 GHz was identified for IMT, but this band is not expected to be available in Europe or in the Americas. This band was already identified for IMT-2000 in China at the WRC-2000. The sub-band 450–470 MHz was identified for IMT globally, but it is not expected to be widely available in Europe. This spectrum will be narrow with a maximum 2 × 5 MHz deployment.

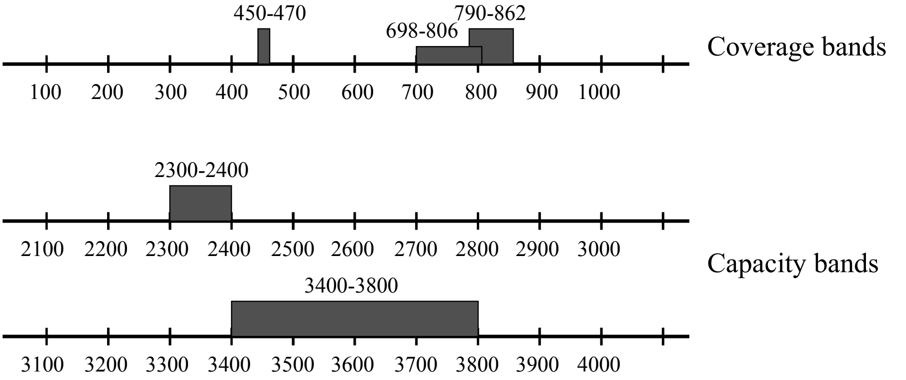

Figure 1.14 Main new frequencies identified for IMT in WRC-07

1.9 LTE-Advanced

International Mobile Telecommunications-Advanced (IMT-Advanced) is a concept for mobile systems with capabilities beyond IMT-2000. IMT-Advanced was previously known as Systems beyond IMT-2000. During 2009, there will be an open call for candidates for IMT-Advanced to be submitted to ITU, as well as the start of assessment activities of candidate technologies and systems. The radio interface submission deadline is expected by October 2009 and the final specifications by 2011.

The new capabilities of these IMT-Advanced systems are envisaged to handle a wide range of supported data rates according to economic and service demands in multi-user environments with target peak data rates of up to approximately 100 Mbps for high mobility and up to 1 Gbps for low mobility such as nomadic/local wireless access. 3GPP has started to work towards IMT-Advanced targets also for the local area radio under the name LTE-Advanced. LTE-Advanced is planned to be part of 3GPP Release 10 and the commercial deployment of IMT-Advanced will be 2013 or later. The high level evolution of 3GPP technologies to meet IMT requirements is shown in Figure 1.15.

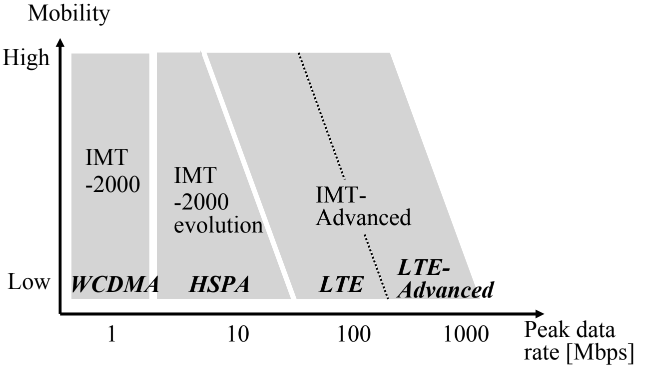

Figure 1.15 Bit rate and mobility evolution to IMT-Advanced