

Beyond 3G / 4G Radio Access Technologies (RATs) and Standards Roadmaps

eMobility Technology Platform Whitepaper

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Introduction

The current wireless landscape over the different regions is characterized by the presence of a plethora of distinct wireless standards (e.g. GSM/DCS/PCS, GSM-EDGE, W-CDMA, HSPA, TD-(S) CDMA, IS-95, CDMA2000, IEEE 802.11a/b/g/n, IEEE 802.16a, DAB, DVB-T, DVB-H...). In the future, it is expected that this landscape will further be enriched by new higher data rate standard (e.g. LTE, UMB, IEEE 802.16m, LTE-Advanced), some of them targeting IMT-Advanced or (more popular notion) 4G status. Moreover, there are additional emerging cognitive standards (e.g. IEEE 802.22, IEEE SCC41) as well as provision of self-organization by standardized interfaces. One classical (historical) reference representation from ITU is depicted in Figure 1.

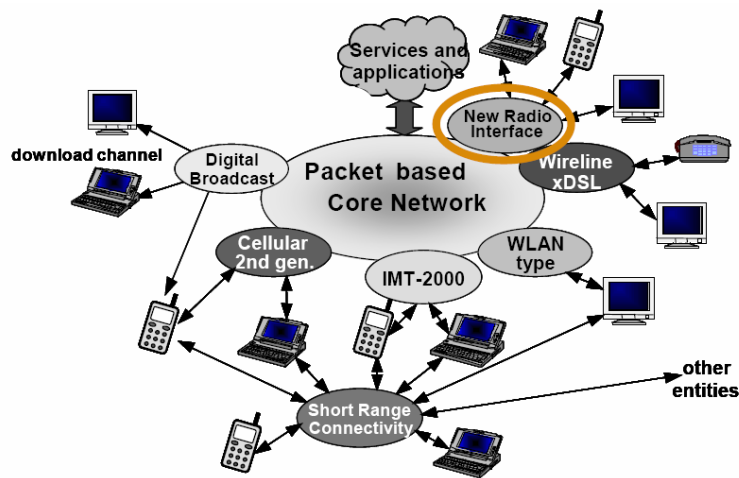


Figure 1: Heterogeneous B3G/4G Landscape [1]

The different radio access technologies fulfil specific requirements and characteristics (e.g. throughput, data rate, range, mobility...) according to initial design requirements. One classical (again historical) reference representation from ITU (known as the Van) is depicted in Figure 2.

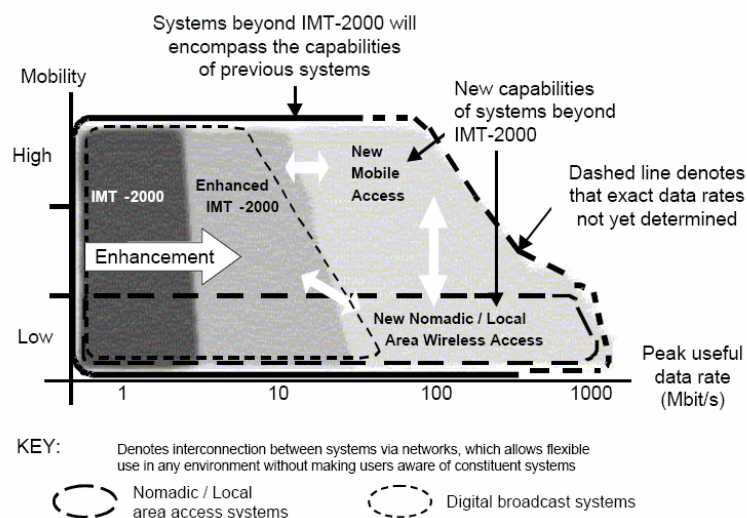


Figure 2: Technology Requirements and Use [1])

There is no doubt that one key capability of a future wireless Radio Access Technology (RAT) is that it should provide truly mobile broadband, i.e. the combination of high capacity and close to full mobility and coverage. The development in the recent year has shown that data traffic in cellular 3G systems (HSPA, EV-DO) has really taken off and is expected to continue to grow rapidly. The increase can be counted in terms mobile broadband subscriptions, number of commercially launched mobile broadband capable networks, and the share of mobile data traffic (versus voice traffic) in these networks. By October 07, there were, according to [2], 147 HSDPA networks launched in 69 countries, and by Q107 there were 7.25 million HSDPA subscriptions (estimated 56.8 million by end-2008). Moreover, in 3G networks the amount of data traffic is now surpassing the amount of voice traffic. That is, there is a large and rapidly increasing market for mobile broadband already for current 3G systems, paving the way for even further enhanced 4G mobile broadband services, and this will likely make the interest in a 4G system even stronger.

The development of the future mobile eco-system, with the introduction of higher data rate RATs can be approached in two distinct ways: Both an evolutionary as well as a revolutionary approach are envisaged. In the revolutionary scenario, the new high data rate RAT (e.g. 4G) is foreseen to replace all existing standards, enhancing the mobile data rate and satisfying the set of requirements of the mobile user as well as of wirelessly interaction machine to machine systems. In the evolutionary case, any new high data rate RAT is seen as *one* new component enriching the mobile/wireless environment, thus complementing all other existing technologies. In the latter case the key challenges are in facilitating dependable and seamless interoperation and interoperability between standards. The high-level system view of Figure 3 [3] depicts one potential vision for this evolutionary wireless telecommunications future, the user being at the center and the overall set of radio access technologies allowing a seamless and efficient end-to-end connectivity. Following this vision, the evolution towards 4G will encompass the introduction of new technology segments, including potential new releases of legacy radio access technologies or/and introduction of radically new radio access systems.

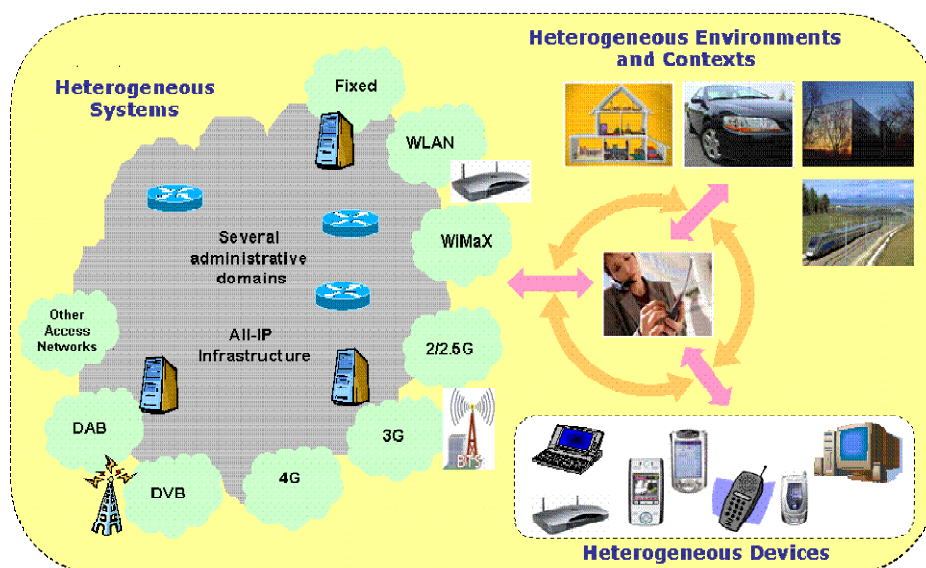


Figure 3: Heterogeneous B3G/4G Landscape [3]

Expanding the statement from N. Schmitz in 2005 [4] *"Ask 10 people what 4G means and you'll get 10 different answers. The more important question is: How do we get there?"*, asking the question today in 2007 "what means B3G, 4G, B4G and 5G" to 10 persons may certainly lead to more than 10 different answers... The eMobility B3G/4G Roadmap Working Group (B3GRM WG) intends with this White Paper to provide some of the answers to this question. The White Paper also provides some indications to approach the *"how do we get there"*. The first section focusses on existing legacy RATs in the different regions, followed by a review of the most relevant international public views on the B3G/4G evolution, and finally a definition of the eMobility perspective on the roadmap for evolution of Radio Access Technologies (RAT) / Standards and related key challenges.

Chapter 1 – International Legacy Wireless Landscape

This section introduces the main different legacy Radio Access Technologies (RATs) of the current and future wireless landscape over the different regions. It also compares their key features and specifications.

The Figure 4 [5] presents a public overview of different radio access technology standards in the coverage / data rate planes.

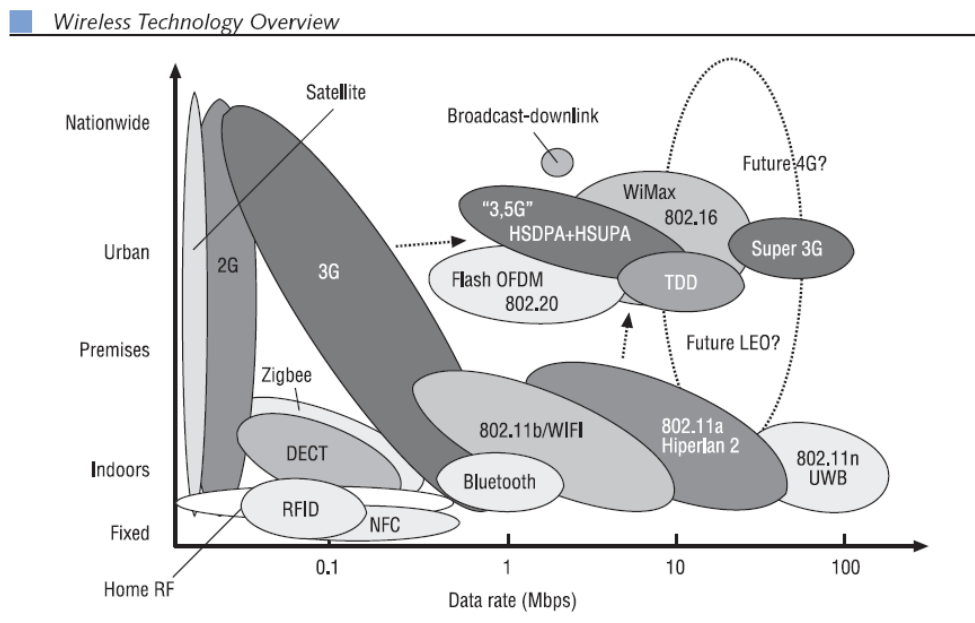


Figure 4: International Legacy Wireless Landscape [5]

This overview reflects a very pertinent summary analysis including several technologies, but not including technologies like LTE or IEEE .16m. All relevant wireless technologies are briefly described in this section and a specific summary figure has been developed by the co-authors, to capture the up-to-date picture (Figure 6).

The characteristics of the different legacy radio access technologies are briefly described hereafter.

NFC

Near Field Communication (NFC) is used in mobile phones for applications like electronic keys, wallet, tickets, identity etc. Data speeds are 106 kb/s, 212 kb/s or 424 kb/s. There are two communication modes, passive and active. In the passive mode, the initiator device provides a carrier field and the target device answers by modulating the existing field. In the active mode, both initiator and target device communicate by generating their own field [6].

RFID

Radio Frequency Identification (RFID) is, in general, used for near field identification of objects or people. In principle, an RFID system is based on one

antenna, one transceiver and one transponder. Transceiver and antenna are usually coupled into one device (reader) which, when operating activates the transponder (the "RFID-tag"), which in turn transmits data back to the transceiver. RFID-tags may be passive, active or semi-passive. While passive RFID's are remote powered by the transceiver, active tags broadcast their information. Like active tags, semi – passive tags have also their own power source, but their transmission is triggered and powered by the transceiver. Different types of systems are available, low-frequency RFIDs (125-148 kHz) and high-frequency RFID systems (13.56MHz), have short transmission ranges (up to 1m). Ultra-high frequency systems (915 MHz) can cover a range up to 10m, while Microwave RFID systems (2.45 GHz) offer transmission ranges of up to 30m [7] [8].

BT

Bluetooth (BT) is a low power radio standard and communications protocol offering short range connectivity between different devices with communication speeds reaching up to 2.1 Mbps. There are three main classes for BT transmission levels: Class 1 (max 100 mW (20 dBm) for a range of approximately 100 meters), Class 2 (max 2.5 mW (4 dBm) for a range of approximately 10 meters) and Class 3 (1 mW (0 dBm) for a range of approximately 1 meter). The protocol operates in the license-free ISM band at 2.45 GHz. To reduce interference, the BT protocol splits the band into 79 channels (each 1 MHz wide) and hops between the channels up to 1600 times per second [9].

Wibree

Wibree is a radio technology for interoperation between small devices. It can be built into products such as watches, wireless keyboards, gaming and sports sensors, which can then connect to host devices such as mobile phones and personal computers. It is essentially the missing link between small devices and mobile devices/personal computers. Wibree fulfills the need for a radio technology that (i) allows communication between small button-cell battery devices and Bluetooth devices, (ii) forms a minimal cost and size addition to Bluetooth devices such as mobile phones and PC and (iii) creates smaller and lower cost options for small button-cell battery devices" [10].

ZigBee

ZigBee technology uses 868 MHz (Europe – 20kb/s), 915 MHz (US – 40kb/s) and 2.4 GHz (worldwide – 250kb/s) ISM bands, enabling regional or global deployment, to provide low data rate wireless applications and offers a published specification set of high level communication protocols designed to use small, low-power digital radios based on the IEEE 802.15.4 standard. The 802.15.4 technology defines PHY and MAC layers allowing for near instantaneous communication between devices without the need for network synchronization delays. These capabilities facilitate to have thousands of devices on a single wireless network. Zigbee is promoted by the Zigbee Alliance and is defined to provide low cost, low power and reliable control and monitoring applications within the private home and industrial environment, such as consumer electronics control, lighting control, access control, HVAC, patient monitoring, security, peripherals management and asset management [11].

UWB

Originally, Ultra Wide Band (UWB) consists in the emission of extremely short pulses with spectral occupancy greater than 500 MHz or 20% of the central frequency. This technology provides good immunity to multipath, better penetration capabilities, low probability of interception, low transmitted power and the possibility of implementing low-cost baseband receivers. Due to the low transmitted

power, UWB systems are inherently devoted to short-range applications such as WPAN, vehicular radar for collision avoidance, sensor networks, identification tags or indoor positioning. Depending on the data rates, UWB technology is divided into short range (few metres) - high data rate (> 480 Mb/s) and longer range (a few tens of metres) - low data rate (10-250 Kb/s). The high data rate is based upon orthogonal frequency division multiplexing (OFDM) scheme, supported by the "WiMedia Alliance" and standardized since 2005 by ECMA (ECMA-368) and ISO (ISO/IEC 26907) since 2007. Applications envisioned are Wireless USB and next Bluetooth generation. The low data rate is standardized by IEEE 802.15.4a since March 07 [12] [13].

IEEE 802.11 Family

IEEE 802.11, commonly known by the brand Wi-Fi, denotes a set of Wireless LAN standards developed by Working Group 11 of the IEEE LAN/MAN Standards Committee (IEEE 802). The term 802.11x is also used to denote the set of amendments to the standard. The term IEEE 802.11 is also used to refer to the original 802.11 (1997), which is now sometimes called "802.11 legacy". The 802.11 family currently includes multiple over-the-air modulation techniques that all use the same basic protocol. The most popular techniques are those defined by the b/g and are amendments to the original standard. Security was originally purposefully weak due to multi-governmental meddling on export requirements and was later enhanced via the 802.11i amendment after governmental and legislative changes. 802.11n is a new multi-streaming modulation technique that has recently been developed; the standard is still under draft development, although products based on proprietary pre-draft versions of the standard are being sold. Other standards in the family (c-f, h, j) are service amendments and extensions or corrections to previous specifications. 802.11b was the first widely accepted wireless networking standard, followed by 802.11g and then 802.11n [14].

IEEE 802.16

The IEEE 802.16 Working Group on Broadband Wireless Access Standards (established by IEEE Standards Board in 1999), aims to prepare formal specifications for the global deployment of broadband Wireless Metropolitan Area Networks. The Working Group is a unit of the IEEE 802 LAN/MAN Standards Committee. A related future technology Mobile Broadband Wireless Access (MBWA) is under development in IEEE 802.20. Although the 802.16 family of standards is officially called WirelessMAN, it has been dubbed "WiMAX" (from "Worldwide Interoperability for Microwave Access") by an industry group called the WiMAX Forum. The 802.16 standard essentially standardizes two aspects of the air interface, the physical layer (PHY) and the Media Access Control layer (MAC). 802.16e uses Scalable OFDMA to carry data, supporting channel bandwidths of between 1.25 MHz and 20 MHz, with up to 2048 sub-carriers. It supports adaptive modulation and coding, so that in conditions of good signal, a highly efficient 64 QAM coding scheme is used, whereas where the signal is poorer, a more robust BPSK coding mechanism is used. In intermediate conditions, 16 QAM and QPSK can also be employed. Other PHY features include support for Multiple-in Multiple-out (MIMO) antennas in order to provide good Non-Line-Of-Sight (NLOS) characteristics (or higher bandwidth) and Hybrid automatic repeat request (HARQ) for good error correction performance. The 802.16 MAC describes a number of Convergence Sublayers which describe how wireline technologies such as Ethernet, ATM and IP are encapsulated on the air interface, and how data is classified. It also describes how secure communications are delivered, by using secure key exchange during authentication, and encryption using AES or DES as the encryption mechanism) during data transfer. Further features of the MAC layer include power saving

mechanisms (using Sleep Mode and Idle Mode) and handover mechanisms. A key feature of 802.16 is that it is a connection oriented technology. The subscriber station (SS) cannot transmit data until it has been allocated a channel by the Base Station (BS). This allows 802.16e to provide strong support for Quality of Service (QoS). QoS in 802.16e is supported by allocating each connection between the SS and the BS (called a service flow in 802.16 terminology) to a specific QoS class. In 802.16e, there are 5 QoS classes: Unsolicited Grant Service, Extended Real-time Polling Service, Real-time Polling Service, Non-real-time Polling Service and Best Effort. The BS and the SS use a service flow with an appropriate QoS class (plus other parameters, such as bandwidth and delay) to ensure that application data receives QoS treatment appropriate to the application [15].

2G

The second generation (2G) of mobile cellular systems has been developed as a successor of analogue systems (called 1G) and became a commercial success in the middle 90's. 2G systems cover a certain number of different technologies among which the most important are: (1) Global System for Mobile Communications (GSM), the more developed technology in the world, in Europe, in many African, Asian and Middle-East countries, and also in American countries (USA, Canada and a lot of South America countries), (2) cdmaOne (also called IS-95), mainly used in the America and Asia-Pacific regions, (3) IS-136 (TDMA, also called D-AMPS), used in North and South America and (4) Personal Digital Cellular (PDC), used only in Japan. These systems offer circuit switched voice and rather limited data rate (e.g. 9.6 kbit/s for GSM circuit mode), which nevertheless opened a new market for mobile data communications through the Short Message Service (SMS). About 360 billions of SMS were sent through GSM networks in 2002. The demand for higher data rates has led to the development of so-called "2G+" or "2,5G" systems. For the GSM technology, the first step has been General Packet Radio Service (GPRS) which offers packet switched transmission at bit rates of about 40 kb/s by allocating several time slots of a frame to the same data transmission. The second step for GSM has been Enhanced Data rates for GSM Evolution (EDGE), which mainly consists in the introduction of the 8-PSK modulation, multiplying by 3 the on-line data rate compared to GPRS. Indeed, EDGE is included in the 3G – IMT-2000 family of systems. IS-95 and IS-136 have also evolved in the same direction. IS-95-HDR implements a packet mode at 144 kb/s (first step towards CDMA2000), while IS-136 has evolved to an EDGE-GSM-based system under the name of Universal Wireless Communications 136 (UWC-136). These technical evolutions aiming to provide more and more efficient data services have paved the way for the definition of 3G systems.

3G

The ITU has deployed a lot of efforts to define a family of systems, called 3G systems, which provide high data rate to offer multimedia services. Under the name International Mobile Communications – 2000 (IMT-2000), these systems have been designed for use in the frequency bands selected by the World Radio Conference (WRC) in the year 1992. The IMT-2000 family is composed of five systems: (1) Wideband Code Division Multiple Access (W-CDMA) including TDD and FDD modes, (2) CDMA 2000 1X, (3) Time Division – Synchronous Code Division Multiple Access (TD-SCDMA), (4) EDGE (also called UWC-136) and (5) Digital Enhanced Cordless Telecommunications (DECT). At the end of the selection phase for IMT-2000, two main families of systems have emerged, leading to the creation of two groups of standardization (including operators and manufacturers), namely: (1) 3rd Generation Partnership Project (3GPP), which developed the W-CDMA standard also called Universal Mobile Telecommunication System (UMTS) in FDD and TDD modes,

and (2) 3GPP2, which developed the CDMA 2000 standards as an evolution of the IS-95 standards. The terrestrial radio interface of UMTS, called Universal Terrestrial Radio Access Network (UTRAN) has been developed through a series of releases, from R3 (also called R99) to R7 which have progressively included a number of features as the FDD mode (R3), the TDD modes – High Chip Rate (HCR) and Low Chip Rate (LCR also called TD-SCDMA) – (R4), downlink data rate of 14.4 Mb/s – High Speed Downlink Packet Access (HSDPA) – (R5), HSUPA for uplink and Mobile Broadcast Multicast System (MBMS) (R6), and finally multi-antennas MIMO techniques (R7). The CDMA 2000 family also comprises a series of standards, from CDMA 2000 1xRTT (using the same RF bandwidth as IS-95) to CDMA 2000 Evolution – Data Optimized (EV-DO) which supports downlink data rates up to 3.1 Mb/s and uplink data rates of up to 1.8 Mb/s for Revision A, and much higher rates for Rev. B (exceeding 10 Mb/s DL obtained by bundling of RF channels) comparable to those of UMTS HSDPA. The continuous evolution and innovation of the UMTS air interface is summarized in Figure 5. The ITU did set guidelines for “3G systems” in the IMT-2000 framework to support data rate 144 kb/s for high mobility and 2 Mb/s in a fixed location. Although the UMTS system met the IMT-2000 guidelines from the start of when Release 99 was standardized, the need for improved spectral efficiency, network optimizations and new services have motivated continued enhancements of UMTS

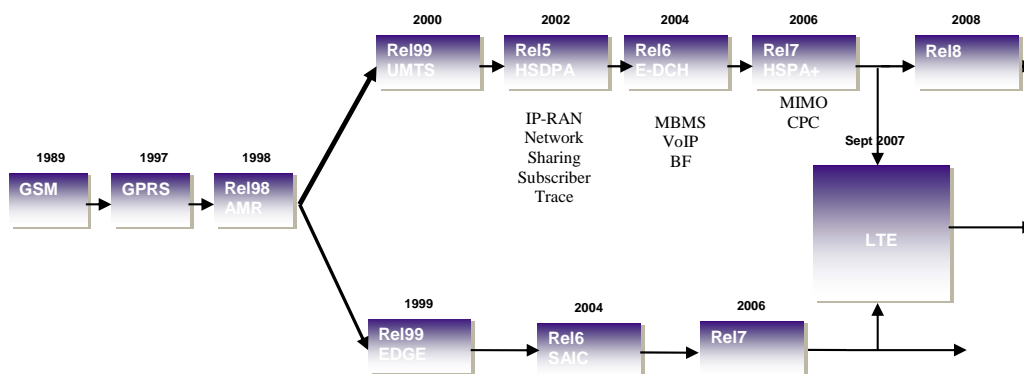


Figure 5: 3GPP UMTS Evolution Plan [16]

In June 02, High Speed Downlink Packet Access (HSDPA) was introduced as part of the UMTS Release 5 standards. The main objectives of HSDPA was to achieve a substantial increase in network capacity, an increase in peak throughputs (up to 14 Mb/s) and a reduction in latency in the downlink. These objectives were achieved by implementing a number of new physical layer and MAC-layer techniques, such as Adaptive Modulation and Coding (AMC), fast scheduling and Hybrid ARQ, all within a new suitable architecture. Enhanced uplink (E-DCH or HSUPA) was introduced in Release 6 to improve uplink spectral efficiency and further reduce the latency. E-DCH, like HSDPA, includes techniques such as fast Node B scheduling, HARQ and shorter frame size. An uplink peak data rate is 5.76 Mb/s is achieved by the introduction of larger code block sizes and/or shorter frame length of 2ms. HSDPA and E-DCH (HSUPA) together, i.e. HSPA, provides a very attractive and efficient UMTS packet system. Still, in order to further enhance the HSPA performance, the evolution and optimization continued for Release 7 to include Continuous Packet Connectivity (CPC) and Multiple Input Multiple Output (MIMO) for the DL achieving 28.0 Mb/s peak data rate. HSPA Evolution (HSPA+) also introduced in Release 7 higher order modulation (HOM) for UL (16QAM) and DL (64QAM).

3G Evolution

HSPA

The evolution of the WCDMA 3G system has been continuous since the first release. As described in the previous section, HSPA was introduced in the Release 5 UTRAN standard. This year (2007), the Release 7 standard will be finalized, which includes 64 QAM and 2 by 2 MIMO, enabling a data transmission rate of 28 Mb/s in downlink and 11 Mb/s in uplink. The HSPA standard provides wireless broadband today, and the packet data traffic in the HSPA networks is likely to increase further during the following years. In 3GPP, the development is planned to continue, and Release 8 (42 Mbps has been mentioned) is expected to be finished in 2008. Further releases promises even higher peak data rates and better performance in general, getting even closer to the performance targets of future 4G systems.

LTE

In the ITU-R work for IMT-Advanced [17] (see ITU in Chapter 2), it has been recognized that in order to reach the full performance set of IMT-Advanced requirements, it is likely that a new radio interface will be needed. Carrier bandwidth of up to 100 MHz is anticipated which would in most cases require new allocations of spectrum (addressed in WRC 07). The requirement of having to obtain additional spectrum triggered an initiative within 3GPP to define a radio interface that was based on the latest developments within the different 4G research activities, but with a bandwidth that would allow for deployments also in spectrum already identified and/or used for 2G and 3G systems. Kick-off of this was end of 2004 under the label "Long Term Evolution" (LTE). In order to ensure 3G competitiveness in a 10-year perspective and beyond, 3GPP then launched this study item of "Evolved UTRA and UTRAN", the aim of which was to study means to achieve further substantial leaps in terms of service provisioning and cost reduction. The overall target of this Long-Term Evolution (LTE) of 3G, sometimes referred to as Super-3G, is to arrive at an evolved radio access technology that can provide service performance on a par with or even exceeding that of current fixed line access, at substantially reduced cost compared to current radio access technologies. The targets of LTE are as follows [18]:

- The possibility to provide significantly higher data rates than do the current steps of 3G evolution (HSDPA and enhanced uplink), with target peak data rate up to 100 Mbps for the downlink and up to 50 Mbps for the uplink,
- The capability to provide three to four times higher throughput and two to three times higher cell-edge throughput (measured at the 5th percentile) when compared to 3GPP Release 6 (Rel-6) systems (i.e. systems based on HSDPA and enhanced uplink),
- Improved spectrum efficiency, targeting an improvement on the order of a factor of 3 compared to current standards,
- Significantly reduced control and user plane latency, with a target of less than 10 ms user plane RAN round-trip time (RTT) and less than 100 ms channel setup delay,
- Reduced cost for operator and end user,
- Spectrum flexibility, enabling deployment in different spectrum allocations. This involves a smooth migration into other frequency bands, including those currently used for second-generation (2G) cellular technologies such as GSM and IS-95,
- One additional requirement is the possibility for smooth introduction of technical solutions that fulfil these targets.

As summarized in [19] LTE RAT is a state-of-the-art air-interface based on OFDM transmission in the downlink and single-carrier FDMA (SC-FDMA) in the uplink providing peak data rates beyond 300 Mbps (DL) and 80 Mbps (UL). LTE makes extensive use of advanced multi-antenna transmission technologies, including both beam-forming for improved coverage and capacity and spatial multiplexing for higher data rates. Furthermore, LTE provides a very high flexibility in terms of system bandwidth, allowing for deployment in spectrum allocations as small as 1.25 MHz up to at least 20 MHz. The high bandwidth flexibility e.g. provides for a smooth migration of current 3G and 3G technologies to LTE. With a support of data rates beyond 300 Mb/s the current specification of LTE already today exceeds the anticipated requirements for IMT-Advanced wide area coverage bit rates. And by utilizing the inherent band width flexibility, the LTE specification can in later releases be complemented with even wider bandwidths and corresponding even higher bit-rates in order to fully comply also with the indoor hot-spot component of the IMT-Advanced (1 Gb/s). Another important aspect of the ITU-R recommendation for "Systems Beyond IMT-2000" is that it identifies the need for a packet-based core network that is common for both 2G, 3G and the "4G" radio access. This will allow operators to roll-out the new radio access as a complement to already deployed radio technologies in a way that is allows that a subscriber is "optimally connected anywhere, anytime". In line with that vision, the LTE specification is written to allow easy co-existence with existing 3GPP radio technologies and facilitate multi-radio end-user devices, without compromising performance. The resulting technology roadmap will enable an operator to introduce LTE in existing equipment and existing frequency band. In later stages, when expanding the bandwidth of LTE to make it comply to also the hot-spot 4G requirements, it will still be possible to cater for legacy LTE terminals on the same wider carrier by allocating those terminals to only a part of the bandwidth, thereby making the introduction of the LTE hot-spot nodes benefit also existing terminal population. The LTE standardization is expected to be finished in 2008 whereas trials will be conducted in 2009 and commercial introduction will start in 2010.

UMB

Ultra Mobile Broadband (UMB) is the brand name for the project within 3GPP2 to improve the CDMA2000 mobile phone standard for next generation applications and requirements. The system employs OFDMA technology along with advanced antenna techniques to provide peak rates of up to 280 Mb/s. Goals for UMB include significantly improving system capacity, greatly increasing user data rates throughout the cell, lowering costs, enhancing existing services, making possible new applications, and making use of new spectrum opportunities. The technology will provide users with concurrent IP-based services in a full mobility environment. The UMB standardization was expected to be completed in mid 2007, with commercialization taking place around mid-2009. To provide ubiquitous and universal access, UMB supports inter-technology handoffs with other technologies including existing CDMA2000 1X and 1xEV-DO systems. The name Ultra Mobile Broadband communicates the key attributes of the technology: (1) Ultra: An ultra fast technology that supports more than an order of magnitude increase in broadband data throughput rates to economically deliver IP-based voice, multimedia, broadband, information technology, entertainment, and consumer electronic services within most kinds of devices, (2) Mobile: A platform that supports several wireless services within a full mobility environment and thus differentiates itself from Wi-Fi, WiMAX, UWB... and (3) Broadband: Ultra high-speeds that are in the order of 100s of megabits per second; next-generation capabilities, beyond 3G [20].

Broadcast

DVB, short for Digital Video Broadcasting, is a suite of internationally accepted open standards for digital television. DVB standards are maintained by the DVB Project, an industry consortium with more than 270 members, and they are published by a Joint Technical Committee (JTC) of European Telecommunications Standards Institute (ETSI), European Committee for Electrotechnical Standardization (CENELEC) and European Broadcasting Union (EBU). DVB systems distribute data using a variety of approaches, including by satellite (DVB-S, DVB-S2 and DVB-SH; also DVB-SMATV for distribution via SMATV), cable (DVB-C), terrestrial television (DVB-T) and terrestrial television for handhelds (DVB-H), and via microwave using DTT (DVB-MT), the MMDS (DVB-MC), and/or MVDS standards (DVB-MS). These distribution systems differ mainly in the modulation schemes used, due to the different technical constraints. DVB-S (SHF) uses QPSK, 8PSK or 16-QAM. DVB-S2 uses QPSK, 8PSK, 16APSK or 32APSK, at the broadcasters decision. QPSK and 8PSK are the only versions regularly used. DVB-C (VHF/UHF) uses QAM: 16-QAM, 32-QAM, 64-QAM, 128-QAM or 256-QAM. Lastly, DVB-T (VHF/UHF) uses 16-QAM or 64-QAM (or QPSK) in combination with COFDM and hierarchical modulation. The DVB project is working on new upgrades of those standards.

Digital Audio Broadcasting (DAB), also known as Eureka 147, is a technology for broadcasting of audio using digital radio transmission. The original objectives of converting to digital transmission were to enable higher fidelity, more stations and more resistance to noise, co-channel interference and multipath than in analogue FM radio. In November 2006, WorldDMB announced that the DAB system was in the process of being upgraded, and it will adopt the AAC+ audio codec to improve the efficiency of the system and stronger error correction coding to improve the robustness of transmissions. This means there are now two different versions of the DAB system: the current one, developed in the late 1980s, and an upgraded version, which has been named "DAB+".

Summary Perspective

The different existing legacy radio access technologies have been developed in accordance to specific requirements in connection to specific use and forecasted services. The main characteristics of standards encompass Throughput, Data rate (uplink / downlink), Range (indoor / outdoor), Spectral efficiency, Quality, Latency, Operational frequency... The detailed RATs summary tables are presented in Appendix. In addition, the summary Table 1 is proposing a relative performance assessment for the different standards. Hence, the review of the characteristics of the standards is extended by listing observations of the qualitative measures of the performances and properties of the standards with regards to the chosen performance assessments criteria as selected in the table. The markings allocated to the standard and assessment criteria are a current perception of the relative status of each standard and are not discriminating and final verdict on the suitability and general quality of the standard. Rather, the table can be considered as information, which can assist intuitive classification and evaluation of the properties of the standard. For example, User Penetration is essentially relevant to the current time of consideration of the standards and can vary and change over the evolution and rollouts of the standards and telecommunications in general. A similar comment is also applicable to other criteria with respect to the change of characteristics over the evolution of deployment. Also, criteria like Range and Mobility should not be interpreted as necessarily discriminating the performance and value of a standard, e.g. Bluetooth and Zigbee is clearly not able to match performances of other some other standards in terms of the coverage and tools for

handling mobility of equipment/users that use it, but this might not be considered as a deficiency of the standard's technology but the property of its intended scope and use.

Technology	Cost	Coverage	User penetration	Throughput	Cost/Bit	Range	Mobility	Frequency	Spectrum type
SHORT RANGE TECHNOLOGIES									
BT	5	1	4	3	5	1	1	2.4 GHz	Unlicensed ISM
Zigbee	5	1	2	3	5	1	1	868 MHz, 915 MHz, 2.4 GHz	Unlicensed ISM
UWB	4	2	1	4	3	2	1	3.1 to 10.6 GHz	Unlicensed Ultrawideband
NOMADIC WIRELESS ACCESS									
WiFi	5	2	4	4	4	2	2	2.4 GHz	Unlicensed ISM
WiMAX-d	4	2	2	3	4	4	1	2.3, 2.5, 3.5, 3.7 and 5.8 GHz	Licensed and Non Licensed
MOBILE WIRELESS ACCESS									
WiMAX-e	3	4	1	4	3	3	4	2.3, 2.5, 3.5, 3.7 and 5.8 GHz	Licensed and Non Licensed
GSM	3	5	5	2	3	3	4	850 MHz, 1.9, 1.9/2.1	Licensed
3G	3	5	5	3	3	3	4	850 MHz, 1.9, 1.9/2.1, and 1.7/2.1 GHz	Licensed (Cellular/PCS/3G/AWS)
HSDPA	3	4	3	4	3	3	4	851 MHz, 1.9, 1.9/2.1, and 1.7/2.1 GHz	Licensed (Cellular/PCS/3G/AWS)
LTE	4	4	1	5	3	3	4	850 MHz, 1.9, 1.9/2.1, and 1.7/2.1 /2.6 GHz	Licensed (Cellular/PCS/3G/AWS)
DVB-T	4	5	4	4 - broad casting	-	4	1	UHF	Licensed
DVB-H	2	2	1	3 - broad casting	-	3	3	UHF	Licensed
	1	2	3	4	5				

Mark: From 1- low/worse to 5- high/best

Cost efficiency: Cost efficiency for each technology deployment (with reference to a single user)

Coverage: Coverage of each technology (area covered by a single access point)

User penetration: Current number of users/terminals

Throughput: Each technology and standard throughput

Cost/bit: Each standard cost per bit

Range: Max. distance to access point

Mobility: Each technology mobility use

Frequency: kind of frequency, licensed or not licensed, regulated at local or global level, etc.

Table 1: RATs / Standards Features / Performances

The wireless community strive towards offering all users broadband everywhere at all times. Mobile broadband has already taken off and will continue to grow. The trend of the mobile wireless access technologies is to achieve higher data rates and still supporting full mobility. Also the nomadic wireless access technologies target the high data rates and have the potential to cover large areas even though mobility is not supported. One common objective can however be identified for both technology tracks, namely to offer broadband access to users independently of time and position, enabling in this case to offer the best seamless experience to the users.

From the technologies listed in Table 1, some of these technologies will see further releases, some will be merged, and some will die, as decided by the industry and the market. There is a clear convergence on technologies and services, for instance broadcasting technologies with data transmission technologies. 4Play and new services invite to that. B3G/4G will include all those components, high data rate, high mobility and high technology complementarity. According to this, this dynamic table is an approximation on the current state of the art, and its evolution will be focus on next generation technologies.

The up-to-date overview of radio access technologies in the mobility / data rate plane (based on [21]) is presented in Figure 6.

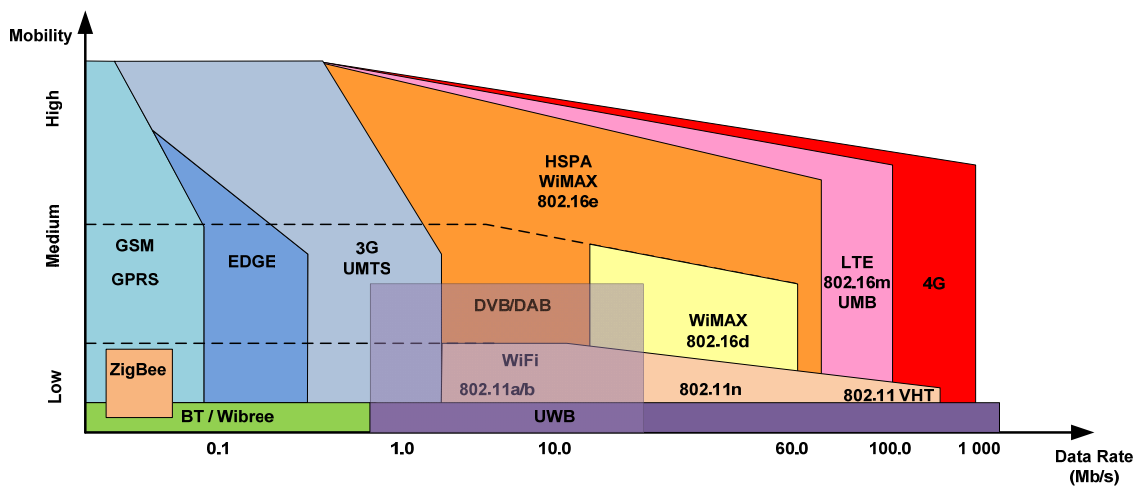


Figure 6: Main Legacy Radio Access Technologies (based on [21])

Chapter 2 - State-of-the-Art for B3G/4G Standards Evolution and Migration

This section is providing a summary of the most relevant worldwide public references for the migration B3G/4G/B4G and the relevant roadmaps of radio access technologies and the migration path towards 4G. This is addressing first international standardization fora, then research and platforms fora, then finally individual companies.

It has to be noted that roadmaps included in this chapter represent different perspectives, from the completion of standard to the first commercialization, passing by the infrastructure deployment.

ITU

The definition of 4G in ITU [1] is addressed mainly by the Working Party ITU-R WP8F "IMT-2000 and systems beyond IMT-2000" and the Special Study Group (SSG) ITU-T "IMT 200 and Beyond". As stated in the mission statements:

- *"WP 8F constructs the future of IMT-2000 and beyond by looking at a long-term vision and coordinating this with spectrum needs. WP 8F considers these broad areas of impact in their work: the needs of the evolving marketplace for future wireless communications, the technologies required to fulfill those needs, the spectrum which is the natural resource of wireless, and the other issues associated with the world-wide advancement of IMT-2000 systems."*
- *SSG "IMT 2000 and Beyond" is responsible for studies relating to network aspects of International Mobile Telecommunications 2000 (IMT-2000) and beyond, including wireless Internet, convergence of mobile and fixed networks, mobility management, mobile multimedia functions, internetworking, interoperability and enhancements to existing ITU-T Recommendations on IMT-2000.*

The ITU roadmap for "IMT2000 and Beyond" is presented in Figure 7.

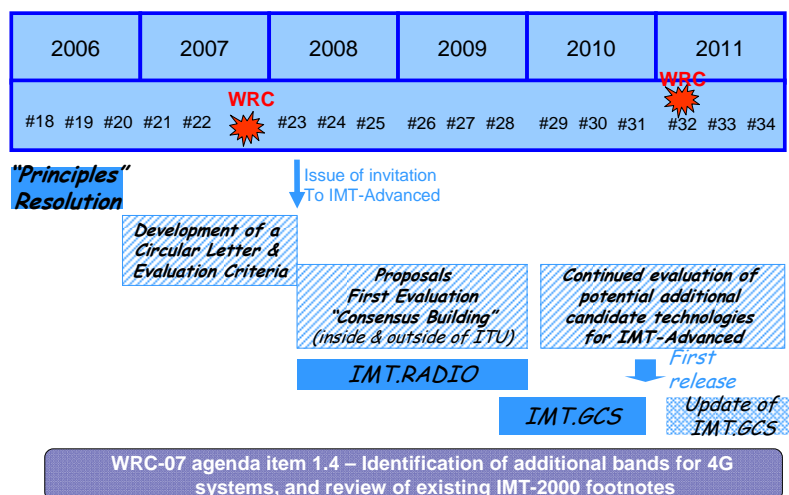


Figure 7: ITU Roadmap [22]

In parallel with the development of activities relative to 4G and Systems Beyond IMT-2000, specific activities have also been started in the context of the evolutionary migration, and the introduction of cognitive radio systems, enabling interoperation between different technologies. The Study Group 8 of ITU-R adopted a question on 12.03.07 (QUESTION ITU-R 241/8) entitled "Cognitive Radio systems in the mobile service". The document says that, considering that a lot of research and development has been carried out on cognitive radio and related topics, and that cognitive radio may facilitate a more efficient use of spectrum in mobile radio system, the ITU-R decides that the following questions should be studied:

1. What is the ITU definition of cognitive radio systems?
2. What are the closely related radio technologies (e.g. smart radio, reconfigurable radio, policy-defined adaptive radio and their associated control mechanisms) and their functionalities that may be a part of cognitive radio systems?
3. What key technical characteristics, requirements, performance and benefits are associated with the implementation of cognitive radio systems?

This Question should be brought to the attention of Study Group 1, 4, 6, and 9.

NGMN

The Next Generation Mobile Networks (NGMN) initiative [23], a group of mobile operators, intends to provide a coherent vision for technology evolution beyond 3G for the competitive delivery of broadband wireless services. The details of the NGMN recommendations are captured in its White Paper, "Next Generation Mobile Networks Beyond HSPA & EVDO" [23]. Figure 8 illustrates the NGMN introduction roadmap overview, showing the coexistence of various technologies and the need for minimization of their diversity. A similar roadmap and statement of minimization of diversity applies to the CDMA2000 family, with NGMN envisioned as the network integrating these evolutionary paths.

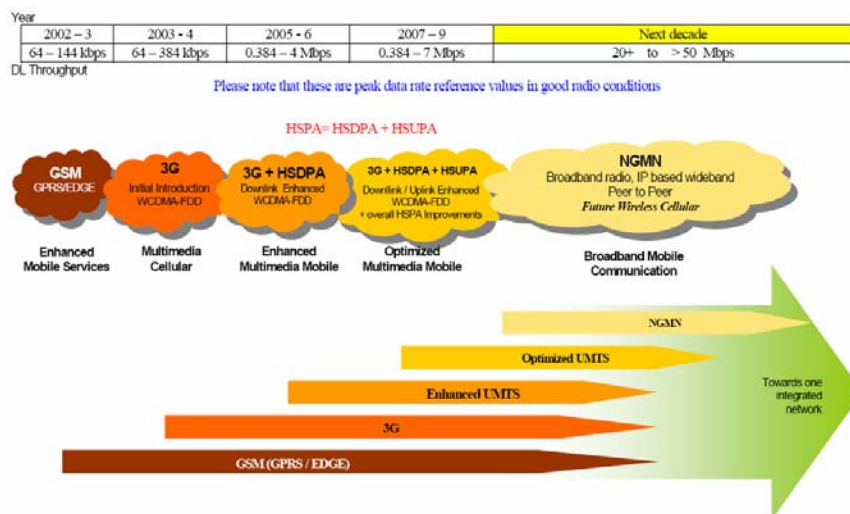


Figure 8: NGMN Roadmap [23])

LTE

There are no 3GPP external documents showing the future roadmap of its activities. However, some data is available from [24]. In this document the result of a LTE evaluation checkpoint is presented, i.e. showing that the standard fulfils and exceeds the target requirements that were set in the beginning of the standardization process. The numbers give an indication on the expected capabilities of the first release of the LTE standard. Tables 2 and 3 below show some of the numbers that are presented in this document. Note that 3GPP at this stage considers two different physical layer frame structures for the TDD mode. The figures in Table 2 and 3 below are valid for the structure referred to as frame structure type 1 (see e.g. [25] for further details).

	Downlink	
Assumptions	64 QAM, R=1 Signal overhead for reference signals and control channel occupying one OFDM symbol	
Unit	Mbps in 20 MHz	b/s/Hz
Requirement	100	5.0
2x2 MIMO	172.8	8.6
4x4 MIMO	326.4	16.3

Table 2: DL Peak rates for E-UTRA FDD/TDD (frame structure type 1)

	Uplink	
Assumptions	Single TX UE, R=1 Signal overhead for reference signals and control channel occupying 2RB	
Unit	Mbps in 20 MHz	b/s/Hz
Requirement	50	2.5
16QAM	57.6	2.9
64QAM	86.4	4.3

Table 3: Peak rates for E-UTRA FDD/TDD (frame structure type 1)

IEEE .16m

The evolution of IEEE .16 is the context of IMT 2000 and Beyond is presented in Figure 9 [26].

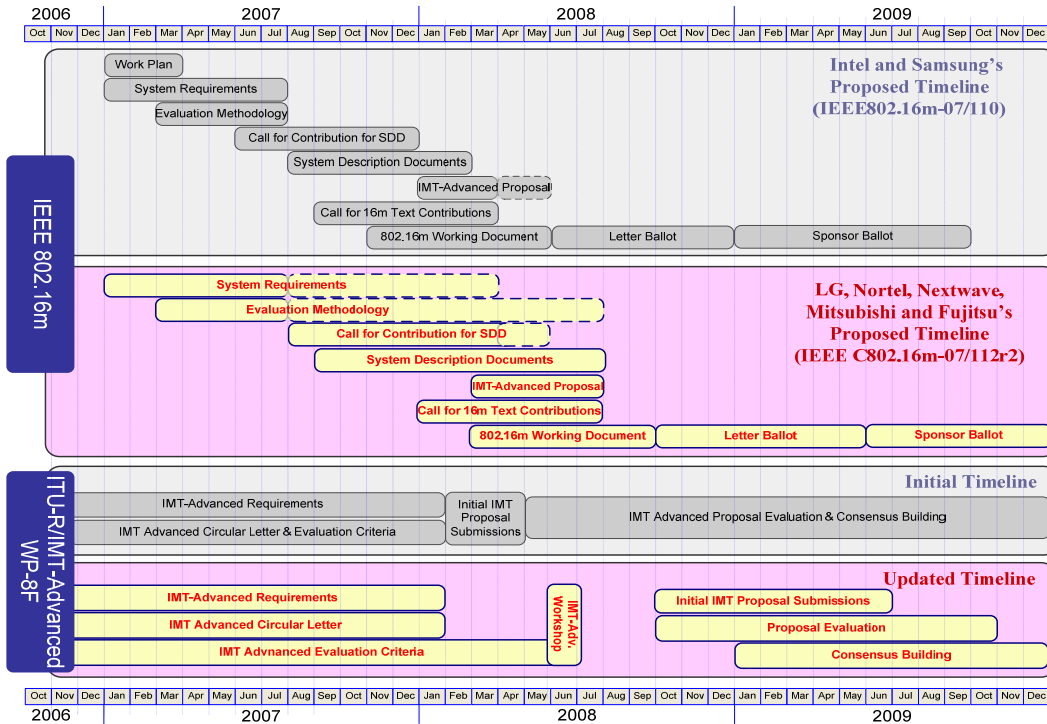


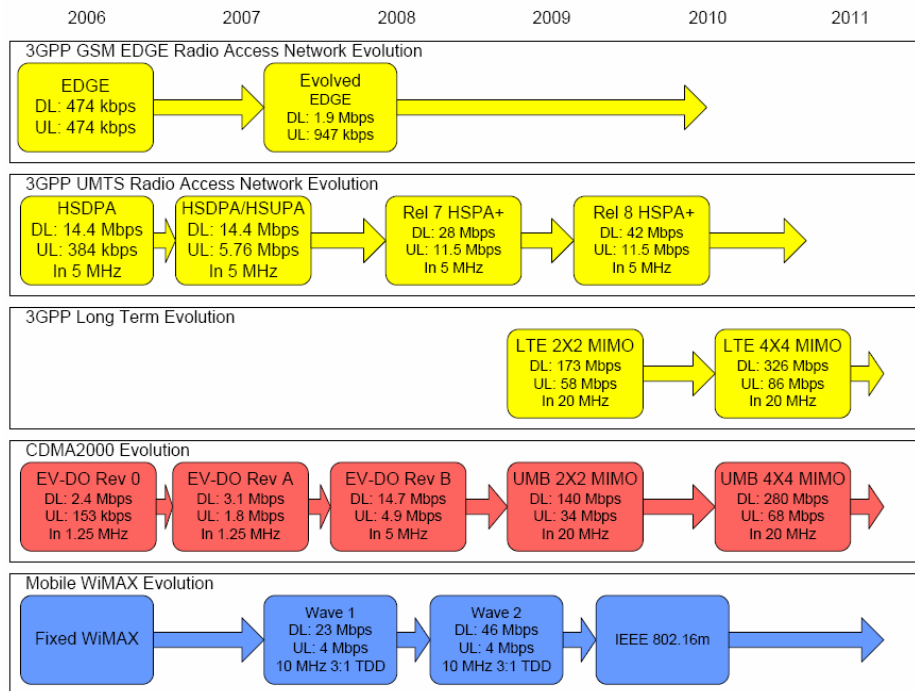
Figure 9: IEEE .16m Roadmap [26]

IEEE .11 VHT

The IEEE 802.11 Very High Throughput (VHT) Study Group is in the phase of creating a project Authorization Request (PAR) and 5 Criteria, analyzing use-cases, technology trends, spectrum requirements. The development of the .11 VHT momentum is considering the priority of .11n completion. The PAR shall be finalized in November 07 and the Task Group is expected to be established in March 08 [26].

3G AMERICAS

3G Americas, LLC [27] unites mobile operators and manufacturers in the Americas to provide a single voice to represent the GSM family of wireless technologies – GSM, GPRS, EDGE, and UMTS/HSDPA. One recent (September 07) roadmap for evolution of 2G, 3G, LTE and WiMAX is presented in Figure 10.



Note: Throughput rates are peak network rates. Radio channel bandwidths indicated. Dates refer to initial network deployment except 2006 which shows available technologies that year.

Figure 10: Radio Access Technologies Evolution [28]

WWRF

The Wireless World Research Forum (WWRF) is a global organization, which was founded in August 2001. It now has over 140 members from five continents, representing all sectors of the mobile communications industry and the research community. The objective of the forum is to formulate visions on strategic future research directions in the wireless field, among industry and academia, and to generate, identify, and promote research areas and technical trends for mobile and wireless system technologies. The forum is structured in six Working Groups and four Special Interest Groups. The forum activities aim towards the creation of a shared global vision for the future of wireless to drive research and standardization. In addition to influencing regional and national research programmes, WWRF members contribute to the work done within the ITU, UMTS Forum, ETSI, 3GPP, 3GPP2, IETF, and other relevant bodies regarding commercial and standardization issues derived from the research work. There has been recently progress made and there is still an ongoing activity on the alignment of views on wireless technologies via liaisons with MITF in Japan, the UMTS Forum in Europe, the NGMC Forum in Korea, and the FuTURE project in China. As part of the effort to shape a common vision for future wireless, WWRF has published a number of White Papers, addressing the technical areas of the Working Groups and the Special Interest

Groups, and the "Books of Visions". The very first Book of Visions was compiled by the WSI Think Tank and published in November 00. A revised version was produced as Book of Visions 2001 and published in December 01. In the end of 2004, Wiley published the next collection of the WWRF White Papers as the Book of Visions 2004. Based on recent contributions to WWRF and White Papers from Working Groups and Special Interest Groups the new Book of Visions 2006 was published in April 06 by Wiley [29]. The next generation wireless system concept, design requirements and enabling technologies as envisioned by the WWRF members are described in the WWRF System Concept document [30]. The key requirements of such a system design are the provision of "high data rate transmissions and highly sophisticated services, comparable to those offered by wired networks and even going beyond. This will be achieved by disposing a system architecture that is distributed, component-based and open. Such architecture will support the capability of context-awareness, personalization and adaptation". In order to achieve these requirements the WWRF system concept will rely on the principles of ambient networking, cognition, dynamic spectrum management, self-organisation and a number of enabling technologies, such as smart antennas, relay-based systems and cross layer designs.

In a recent contribution submitted by several members of the WWRF Vision Committee as a circular letter to ITU-R [31], the next generation wireless system requirements have been addressed from the points of view of the market needs, service and access providers perspectives and infrastructure and devices manufacturers perspectives. Furthermore, the most relevant radio access network parameters/features have been presented and the critical regulatory limitations were discussed.

MITF

The evolution of technologies publicly available from mITF [32] is provided in Figure 11.

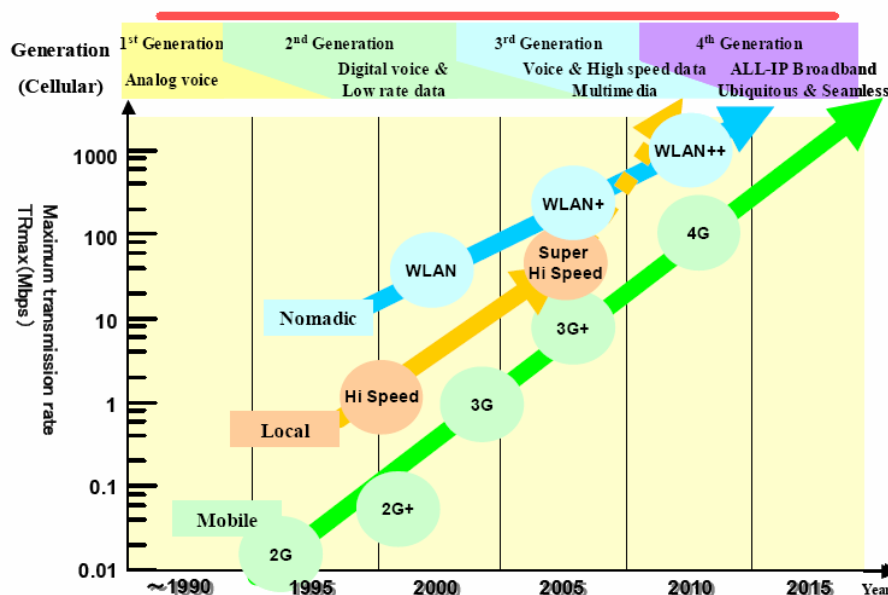


Figure 11: mITF Roadmap [32]

Future+

The evolution of radio access technologies as proposed by the China Fora [33] is provided in Figure 12.

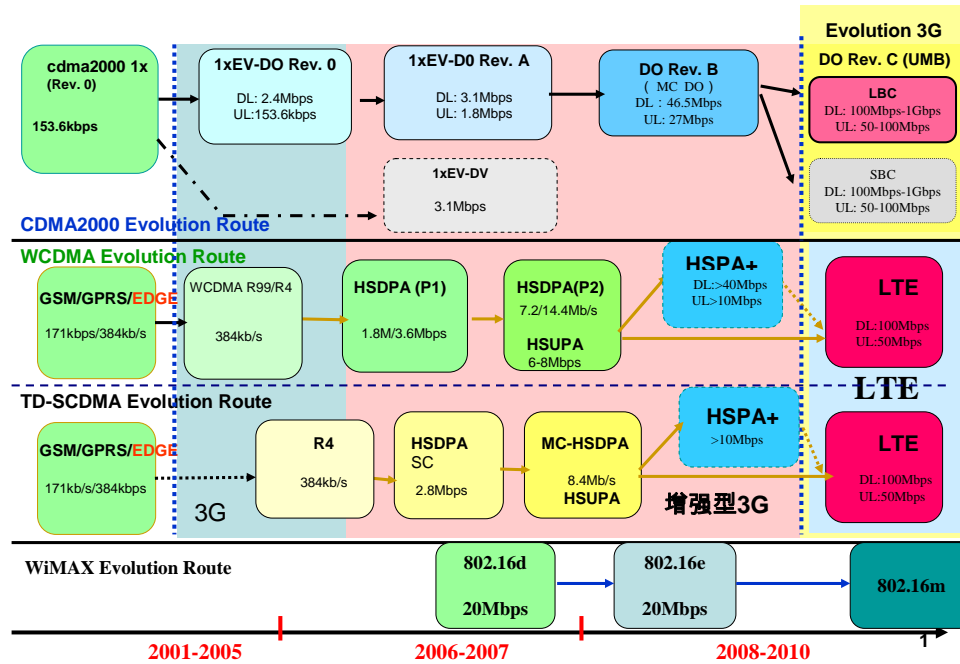


Figure 12: China Fora Evolution Roadmap [33]

Industry Roadmap - Samsung

One migration path towards 4G/B4G for Samsung is presented in Figure 13 and Figure 14. Figure 13 encompassed both evolutionary aspects on mobile and nomadic, towards a revolutionary approach, Wibro being the connected technology in the B3G evolution.

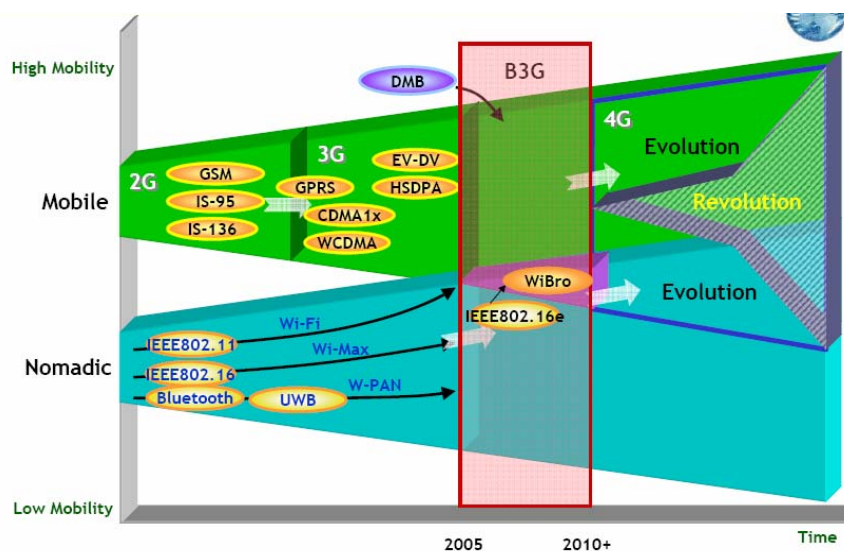


Figure 13: Samsung Roadmap [34]

Figure 14 is expanding/up-dating this vision, reaching the 4G in IMT-advanced through LTE and .16m.

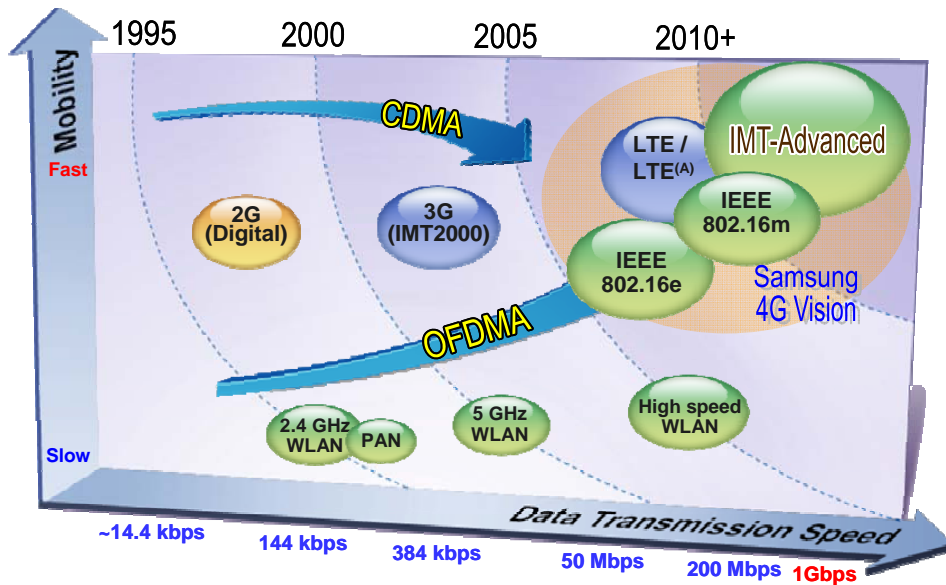


Figure 14: Samsung Roadmap [35]

Industry Roadmap – Alcatel-Lucent

One migration path towards 4G/B4G for Alcatel-Lucent is presented in Figures 15 and 16.

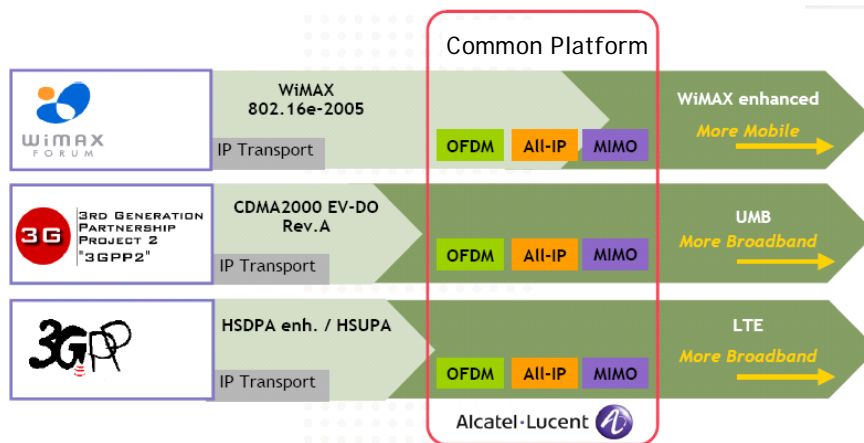


Figure 15: Alcatel-Lucent Technology Roadmap from 2G/3G to Next Generation Wireless Roadmap [36]

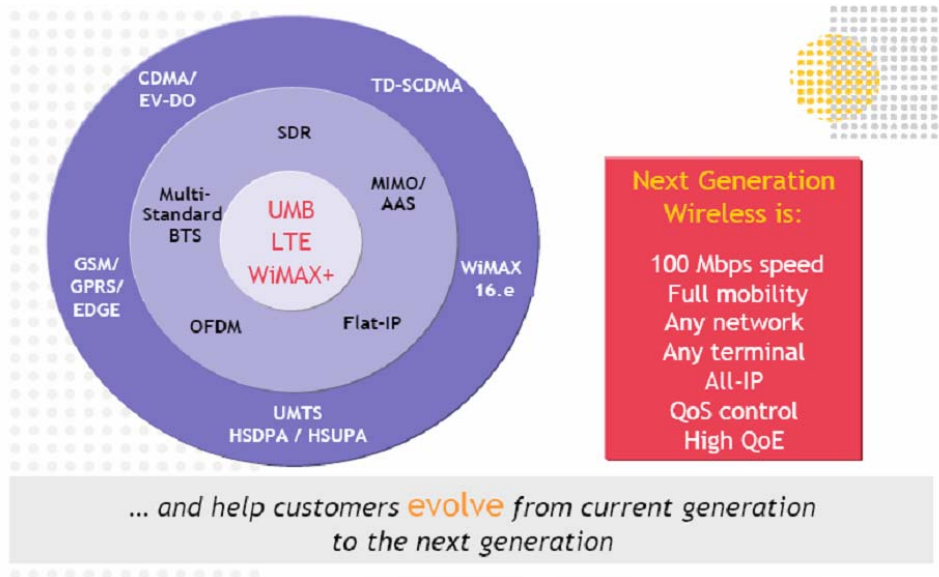


Figure 16: Alcatel-Lucent Technology Roadmap from 2G/3G to Next Generation Wireless Roadmap [36]

Industry Roadmap – Motorola

One migration path towards 4G/B4G for Motorola is presented in Figure 17. This convergence towards 4G/B4G and Broadband Wireless Access is relying on three main pillars, 3GPP LTE, IEEE .16m and 3GPP2 EVDO.

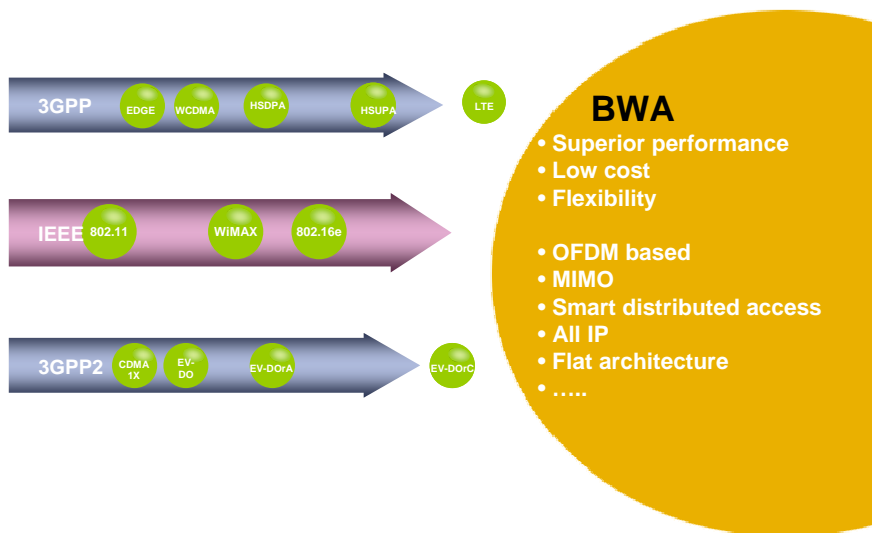


Figure 17: Motorola Roadmap [37]

Industry Roadmap – Picochip

The roadmap presented in Figure 18 display the view from Picochip and has the interest to present the roadmap in a time / data-rate perspective.

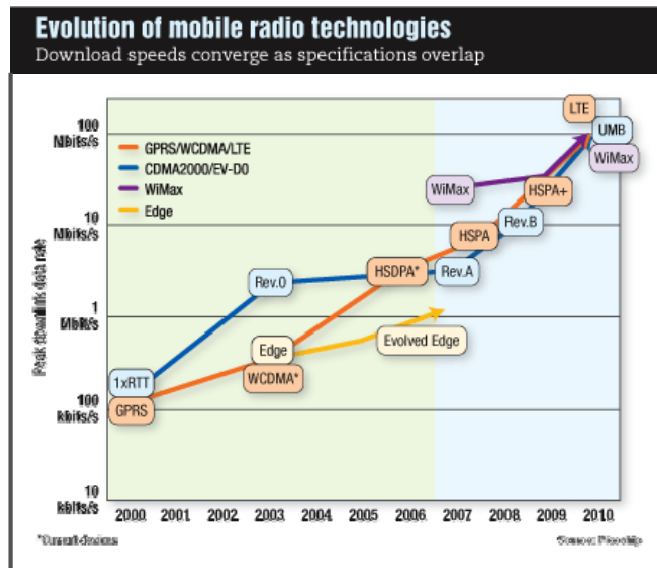


Figure 18: Picochip Technology Roadmap [38]

Industry Roadmap – Ericsson

Packet data traffic in mobile cellular networks has already taken off. In the future, it is expected that two-thirds of the total number of broadband subscriptions will use mobile broadband [39]. Ericsson expects that the technologies offering broadband services to these consumers are (evolved) HSPA [40], which is already in commercial use offering a downlink data rate of 14 Mbps in commercial networks next year (currently (October 07) providing 7.2 Mbps), and LTE, demonstrated to provide more than 150 Mbps at 3GSM this year. A natural next step along this track will be LTE-Advanced, i.e. an IMT-Advanced qualified further release of LTE. Besides from the LTE track a continued evolution of HSPA towards even higher capabilities is foreseen.

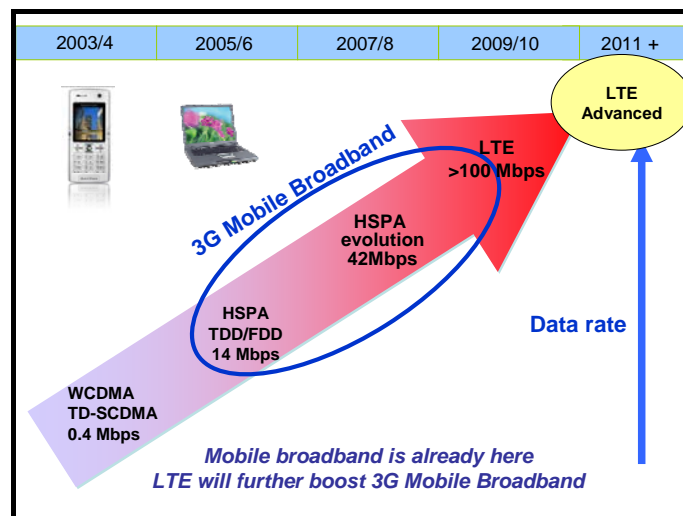


Figure 19: Ericsson’s Roadmap Towards Future 4G Standards [39] [40]

There are several ways to depict the evolution towards 4G and B4G, as depicted in this Section. However, consensus is reached on the key segments to serve as pillars to this evolution (e.g. LTE, UMB, .16m). Challenge will reside in the development, introduction and coexistence of these standards (including coexistence with the existing legacy ones), and the definition of the most relevant migration scenario (dependent of business, standardization...).

Chapter 3 - eMobility Roadmaps and Migration and associated B3G/4G Challenges

Based on the review of existing legacy radio access technologies (Section 1) and the review of existing public perspectives for the roadmaps of these radio access technologies evolutions (Section 2), this section is presenting the e-Mobility perspective on what is, should or could be the B3G/4G/B4G evolutionary or revolutionary path. The section will identify the most relevant options and address the key technical challenges. It is obvious that the future path (*"how do we get there"*) will be highly dependent on the region (ITU region) and the overall markets dynamics.

What is B3G/4G/B4G/5G

When addressing B3G and 4G, it is commonly agreed that the B3G/4G telecommunications world will rely on an all-IP integrated network, serving best end-users at any time and any location, with higher data rates than the ones available today. Public source on B3G/4G defines 4G as [41]

"4G will be a fully IP-based integrated system of systems and network of networks achieved after the convergence of wired and wireless networks as well as computer, consumer electronics, communication technology, and several other convergences that will be capable of providing 100 Mbit/s and 1 Gbit/s, respectively, in outdoor and indoor environments with end-to-end quality of service and high security, offering any kind of services anytime, anywhere, at affordable cost and one billing."

As pointed in [42]

"4G is an evolution not only to move beyond the limitations and problems of 3G, but also to enhance the quality of services, to increase the bandwidth and to reduce the cost of the resource."

Considering that 3GPP LTE, IEEE .16m can be considered today as 4G, IMT Advanced as B4G, it shall be reported that researchers started already to address potential 5G. As pointed in [42]

The idea of WWW, World Wide Wireless Web, is started from 4G technologies. The following evolution will based on 4G and completed its idea to form a REAL wireless world. Thus, 5G should make an important difference and add more services and benefit to the world over 4G; 5G should be a more intelligent technology that interconnects the entire world without limits.

Based on Sections 1 and 2, the B3G/4G/B4G can be mapped on technologies, according to Figure 20.

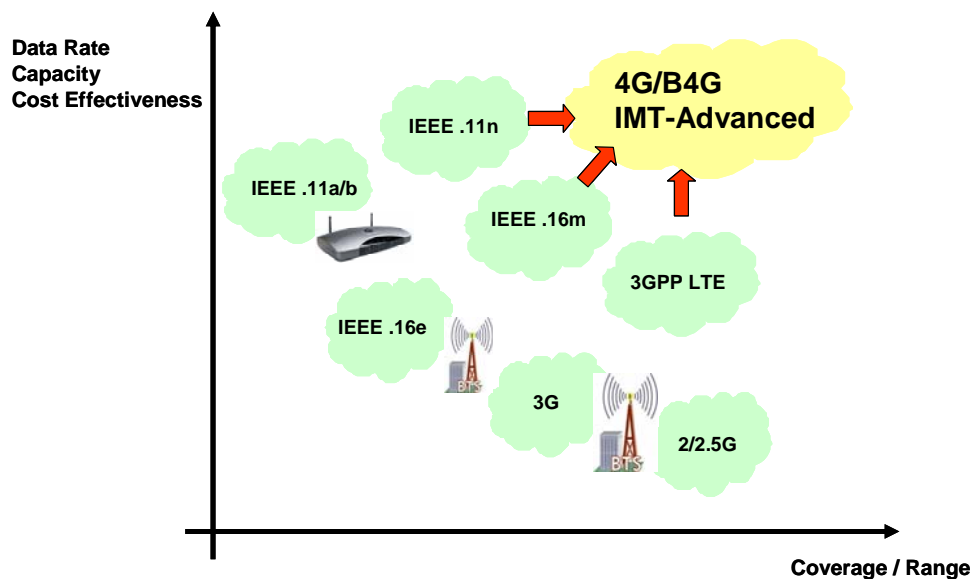


Figure 20: 4G/B4G (Based on [43])

In the vision of future mobile usage, in addition to existing legacy applications and services, there will be new types of usage opportunities and kinds of applications will become possible, when mobile devices not only present data but also gather and provide information to other users. Users will be able to act as service and content producers and providers of instant services with information, contents and knowledge [44]. Mobile devices will facilitate distribution of knowledge that can then be used remotely by other users, with their mobile devices. Considering the amount of available knowledge in such an environment as well as the uncounted potential information sources, the actual information provided will need to be constantly updated, relevant to the users interest and according to their context. To enable every mobile user to become a service provider with their mobile device, the mobile platforms will need to be simple, accessible and efficient. User-friendly creation tools in the mobile, optimised execution environment, a model for knowledge warehouse, search engines and a set of business models for the producers and providers of new services and content will be required. Key challenges for 4G/B4G/5G applications and services will reside in the right definition of (1) User and group profiling (based on e.g. content-based approaches or/and collaborative filtering approaches), (2) Multimodal interfaces (e.g. currently very popular applications which are integrating modality input such as speech and pen gestures in map navigation applications, navigation in 3D applications for construction or in games...), (3) Community based services [45] group support and group management (online-communities is one of the most valued creating forces of the internet economy), (4) Folksonomies/tagging (social tagging, social bookmarking will significantly enhance the efficiency of information sharing by labelling of the content items being shared) [46], and (5) Social collaboration systems (including recommendation tools) [47]. All these new applications and services will clearly create new requirements on wireless technologies in terms of bandwidth, latency, end-to-end quality of service, trust...

To facilitate a communication infrastructure and environment where the complex requirements that come along with such applications and services can be met, there will need to be sufficient support from both the underlying networks and service platforms, but also the actual wireless access systems. Looking at the evolution of wireless access systems for 4G/B4G/..., such systems will be required

to provide the means to support technical solutions that can cope with the following trends:

- User expectations shift from wired broadband access towards wireless anytime/anywhere access, supported by the convergence of services and devices, and the requirement to support both home as well as office Ethernet-class type of applications and services),
- Operator expectations to deliver mobile broadband Internet experience to the user at a low CAPEX/OPEX, relying on flexible solutions to address a variety of needs and deployment scenarios,
- Spectrum bands currently under identification.

As a consequence, this could translate into the following challenges for the telecommunication industry:

- Improved performance
 - Increase of spectral efficiency in particular at cell edge (consistency of performance throughout cell),
 - Important for Peak/average data throughputs (inner Cell/Cell edge),
 - In discussion up to 20b/s/Hz,
 - Lower and consistent latency to support advanced applications such as interactive gaming
 - For Userplane (interactive gaming): < 10ms Roundtrip time in RAN,
 - For Control plane: Shorter Radio Bearer setup times (< 100ms),
 - Support of more users per cell with packet services
 - 500 parallel users per 20 MHz band (example),
 - Increase of data rates
 - Nominal data rate of 100 Mb/s in mobile conditions,
 - Up-to 1 Gb/s in fixed conditions,
- Lower cost
 - Flat architecture: Lower number of Nodes, less open interfaces, less complexity,
 - Efficient backhauling: Higher bandwidth for less cost,
 - Improved performance, that has also an impact on CAPEX,
- More flexibility
 - Interworking solutions between different radio technologies, including support of delay-sensitive applications,
 - Self-management/self-configuration,
 - Support of hotspots and hotzones including indoor,
 - Systems with minimized OPEX for the operator,
 - Service evolutions (User centric services in 2G Internet).

According to one specific EC development initiative, namely [16] the enhanced system capabilities include:

- A sustainable "high end" data rate (above layer 2) per link of 50 Mb/s. This is not an instantaneous data rate but the data rate achieved over the period of activity of a service.
- A consistent and ubiquitous data rate per link of 5 Mb/s (above layer 2), to be provided throughout any arbitrary intended geographic service area,
- A minimum delay over the air interface measured at layer 2 of 1ms,
- Peak spectral efficiency in connected sites of 10 b/s/Hz/site in wide area deployments for high load,
- Peak spectral efficiency in isolated (non-contiguous) sites of 25b/s/Hz/site,
- Range of single service traffic symmetry (not including broadcast or one-way services) to be supported 10:1 to 1:10 over the time of an active session of the service,

- The symmetry of the long-term (measured over at least one day) aggregate user traffic within the system will be 1:2 to 2:1.
- Broadcast and multicast will be supported,
- Peer-to-peer and Ad-Hoc operation will be supported,
- User speeds of 0-500km/h will be supported in order to support users in a range of situations from stationary, through pedestrian and vehicular to high-speed trains (500km/h).

Other system requirements in this area cover location accuracy and other context information, coverage, packet channel establishment, inter-working with IP networks and access system sharing. The services requirements include the seamless application access for the user, the support of IP as a service level protocol and a negotiable QoS, including renegotiation during an active session. The requirements for interworking on radio access level cover the legacy systems identified for inter-working, network selection control and seamless handover.

In comparison to 3G systems, beyond (B3G/4G) should aim for a decrease in the total cost of ownership and the costs per bit by a significant factor. In particular the following areas could be considered to allow enhanced radio cost efficiency:

- Backhaul from base stations is a significant source of cost. Optimized backhaul solutions and meshed networks for self-backhauling and dynamic transport routing is a potential solution,
- Cost-optimized indoor nodes, which allow for large-scale economically viable deployment by plug-and-play,
- Platform migration from existing system architecture towards a cost-optimized architecture, e.g. by introduction of simple aggregation devices,
- Self-organization principles to support automation of operational tasks such as network planning, configuration and optimization as well as self-healing concepts to minimize operational effort and hence cost,
- Provision of system equipment sharing between network operators. This includes the provision of open interfaces and cost efficient mechanisms to monitor and enforce agreed Service Level Agreements as part of simple end-to-end Operations & Management systems.

Some enabling factors (challenges) for acceptable flat rates for the end-users could be:

- CAPEX Saving aspects
 - Optimised spectral efficiency (Better usage of HW platforms): OFDM, MIMO, Packet Scheduler, Interference Mitigation, Collaborative/Network MIMO, SFN operation for Mobile TV,
 - Maximum reuse of installed base: Multistandard/multiband Configurations by SDR and Cognitive Radio,
 - Less backhauling cost: Meshed networks and relay backhauling (TDD solutions), Better usage of capacities according traffic occurrence,
- OPEX saving aspects
 - Efficient Amplifiers: Less operational costs,
 - Selfconfiguration plug and play solutions: Less network planning effort, less experts needed on operator and vendor service side,
 - Selfoptimization: Less operational cost, less experts needed on operator and vendor service side.

According to one specific EC development initiative [16] some important characteristics of a future wireless system are:

1) Spectrum and co-existence

The WINNER System Concept should be able to operate anywhere in range between 2.7 - 5.0 GHz.

- The new radio access will have to be able to utilise also the bands currently identified for IMT-2000 in 800/900 MHz, 1800/1900 MHz, 2 GHz and 2.6 GHz frequency ranges or other frequency bands that may become available below 2.7 GHz.
- The total system bandwidth needed to fulfil the requirements should be minimised.
- Maximum required bandwidth for one radio link: 100 MHz. It is important to note that this (which is linked to the implementation requirements) is an upper limit not a fixed value. The spectrum allocations for beyond IMT-2000 are as yet unknown.
- Minimum required bandwidth per duplex radio link: 2.5 MHz

Requirements are also defined on co-existence and use of fragmented spectrum.

2) Implementation

Many of the requirements on implementation at this stage are more general on issues such as complexity, power, scalability and reconfiguration and will be defined further in Phase II of WINNER. Specific requirements identified are:

- Macro-cellular antenna hardware must be minimised. Maximum antenna radome width should be 450 mm as a flexible target for the WINNER project.
- The system shall be able to be deployed without Inter-site time synchronisation. If inter-site-time synchronisation becomes part of the WINNER system concept, operation without it shall be possible.
- The number of devices and platforms should not be limited, but the minimum number needed should be low.
- It is assumed that the highest possible modulation order for a mobile operating at 100MHz is 64QAM (due to power consumption issues of analogue-to-digital conversion).
- There are requirements on terminals relating to scalability/reconfigurability, power consumption, talk/ standby times and thermal issues.

Some of the key challenges for the evolutionary path reside in the guarantee of true end-to-end connectivity in the heterogeneous wireless world, building on cognitive radio systems (cognitive radio, cognitive networks and radio enablers) [3]. Cognitive radio systems are seen by many actors of the wireless industry as a core technical evolution towards exploitation of the full potential of B3G/4G systems. It is under way to revolutionise wireless communications just as the PC revolution did in its domain. Seamless access to both applications and services as well as exploitation of the full diversity of corresponding heterogeneous systems, shall offer an extensive set of operational choices to the users (e.g. seamless experience), application and service providers (e.g. fast deployment of enhanced features and services in reduced time frames), operators (e.g. network management, operation and maintenance), manufacturers (e.g. wider market and migration to new standards) and regulators (e.g. increasing spectrum efficiency). The use of the radio resources and spectrum shall be optimized, following cognitive radio and cognitive network paradigms (autonomic management, learning, experience, knowledge as well as context, profiles, policies). The management functions will be distributed over different network elements at various levels of the system topology. A corresponding management

agility will be required for supporting the most efficient use of the cooperating technologies, at local, regional, and global levels. The evolution of wireless systems shall be achieved in an evolutionary, non-disruptive way, by integrating existing wireless radio standards into a common framework with user devices being able to reconfigure and maintain one or multiple links simultaneously.

The technical challenges include:

- Managing complex architectures and managing and controlling interoperability, scalability and flexibility in B3G/4G wireless heterogeneous networks,
- Reducing cost of deployment, evolution and operation of B3G/4G large communication systems,
- Enabling a seamless experience for the end user and the operators and understanding the roles (and evolution of role) of traditional and new stakeholders in cognitive radio systems,
- Defining the B3G/4G system architecture based on the concept of cognitive control functions (context awareness, decision-making based on adaptive algorithms and performing appropriate reconfigurations),
- Optimizing the use of spectrum and radio resources by means of cognitive network mechanisms and semi-distributed collaborative decision-making between network elements and user terminals,
- Supporting peer-to-peer based (collaborative) optimisation of radio environments, in which individual nodes may deploy cognitive mechanisms to set up the initial configuration as well as to optimise their configurations and parameter settings,
- Optimizing the dynamic usage of spectrum and radio accesses in a multi-operator scenario without any centralised control entities,
- Minimizing the complexity of autonomous/self-x functionalities of cognitive radio systems,
- Defining and engineering means that enable RRM and DSA procedures across heterogeneous standards coexisting with existing RRM procedures in legacy systems and aligned with the IMT-Advanced requirements,
- Defining and engineering the Cognitive Pilot Channel (CPC) as technical enabler for cognitive radio systems.

Regarding the forthcoming B3G/4G/B4G evolution, one very important milestone resided in the discussions and decisions to be held during the World Radio Conference (WRC) organized on 22.10-16.11.07 in Geneva [48]. The WRC-07 looked for worldwide harmonised frequency bands for the further development of IMT-2000 and IMT-Advanced. Within the Agenda Item 1.4 "New spectrum for 3G and 4G applications" two main objectives were resolved: Additional frequency bands below 1 GHz for improving coverage and additional frequency bands above 1 GHz to provide sufficient capacity in high data rate mobile radio applications. In total close to 400 MHz of new spectrum for IMT was allocated:

- Coverage bands (in total 92 MHz): Table allocation for 450 - 470 MHz plus 790 – 862 MHz (from 17 June 2015 onwards) in Region 1 (Europe, Africa) from Digital Dividend. For the Americas for the higher frequency range 698 – 862 MHz was allocated. Use of the higher frequency ranges will be possible by existing/new Footnotes in most European countries before 2015. Further sharing studies for the higher frequency range should be provided for and reviewed during WRC-11,
- Capacity bands (in total 300 MHz): Table allocation for 2300 – 2400 MHz plus Footnote allocation for 3400 – 3600 MHz in Region 1 and 3 with the restriction that 3500 – 3600 MHz is not available in the Americas and only 3400 – 3500 MHz is harmonized among all ITU Regions.

It should be noted that none of the bands are immediately available due to current use by other applications. Since the allocated spectrum of 392 MHz is only one third of the expected requirement at around 2020 it was concluded that further studies shall be conducted and reported to WRC-11. A further protection of UMTS expansion bands (Agenda Item 1.9) was concluded at WRC-07 by removing Mobile Satellite Service (MSS) in the bands 2500 – 2520 MHz and 2670 – 2690 MHz for Europe, Africa, Arabic Countries and the Americas. Furthermore power flux density values on the surface of the earth have been significantly tightened for new satellite systems to protect mobile systems against interference.

During WRC-07 [48], the agenda adopted for next WRC-11 (Resolution [COM6/7] (WRC-07), "Agenda for the 2011 World Radiocommunication Conference"), includes two important items (1.2 and 1.19) related to convergence and cognitive radio:

- 1.2: *Taking into account the ITU-R studies carried out in accordance with Resolution 951 (Rev.WRC-07), to take appropriate action with a view to enhancing the international regulatory framework;*
- 1.19: *To consider regulatory measures and their relevance, in order to enable the introduction of software-defined radio and cognitive radio systems, based on the results of ITU-R studies, in accordance with Resolution [COM6/18] (WRC-07);*

The item 1.2 refers to Resolution 951 (Rev. WRG-07) entitled "Enhancing the international spectrum regulatory framework" which says that, considering the emergence of new radiocommunication technologies that will allow more flexible sharing of the spectrum and thus more efficient use, and their convergence, the international spectrum regulatory framework should be amended accordingly. It resolves:

1. *that, as a matter of urgency, taking into account Annexes 1 and 2, studies are to be continued by ITU-R, in order to develop concepts and procedures for enhancing the Radio Regulations to meet the demands of current, emerging and future radio applications, while taking into account existing services and usage;*
2. *that the studies mentioned in resolves 1 shall be limited to general allocation or procedural issues relating to general spectrum management solutions, such as those already developed in Annex 1, in line with the process contained in Annex 2;*
3. *to invite WRC-11 to take into consideration the results of these studies, including sharing and their impact on allocations in the concerned frequency bands, and take appropriate action in accordance with Annex 2.*

It invites ITU-R "to conduct the necessary studies in time for consideration by WRC-11 and in accordance with this Resolution," and invites administrations "to participate actively in the studies by submitting contributions to ITU-R.."

The item 1.19 refers to resolution 18 (RESOLUTION [COM6/18] (WRC-07)) on cognitive radio, entitled: "Regulatory measures and their relevance to enable the introduction of software defined radio and cognitive radio systems." The document says that, considering the large amount of work that have been carried out in the area of cognitive radio and spectrum management (citing Question ITU-R 241/8 and Report ITU-R M.2064), considering the possibility to enhance a multi-RATs network performance through assistance of a dedicated cognitive pilot channel, the Resolution resolves to invite ITU-R:

1. *to study whether there is a need for regulatory measures related to application of technologies of cognitive radio systems;*

2. to study whether there is a need for regulatory measures related to the application of software defined radio,
and further resolves that "WRC-11 consider the results of these studies and take the appropriate actions."

The ITU-R Study Group or Working Party that will be tasked with this work will be identified and starting the work early 2008.

The discussions and decisions held during WRC 07 will clearly have an impact on the forthcoming development of the wireless ecosystem and the "...how do we get there..." mentioned in the Introduction of this White Paper.

It is obvious that the migration towards 4G/B4G systems will rely on evolution of wireless radio access technologies but also on networking technologies. One potential migration scenario, discussed in the context of EC concertation and cluster meetings, based on publicly available information is depicted in Figure 21. This figure is clearly addressing the three main axis for wireless evolution detailed in chapter 2 (WiMAX, LTE and 4G), also identifying the two key challenges of Next Generation Networks (NGN) and Future Internet. Most of the research challenges both on air interface, network and user equipment sides are addressed inside the eMobility ETP context, being investigated by the different FP7 research projects.

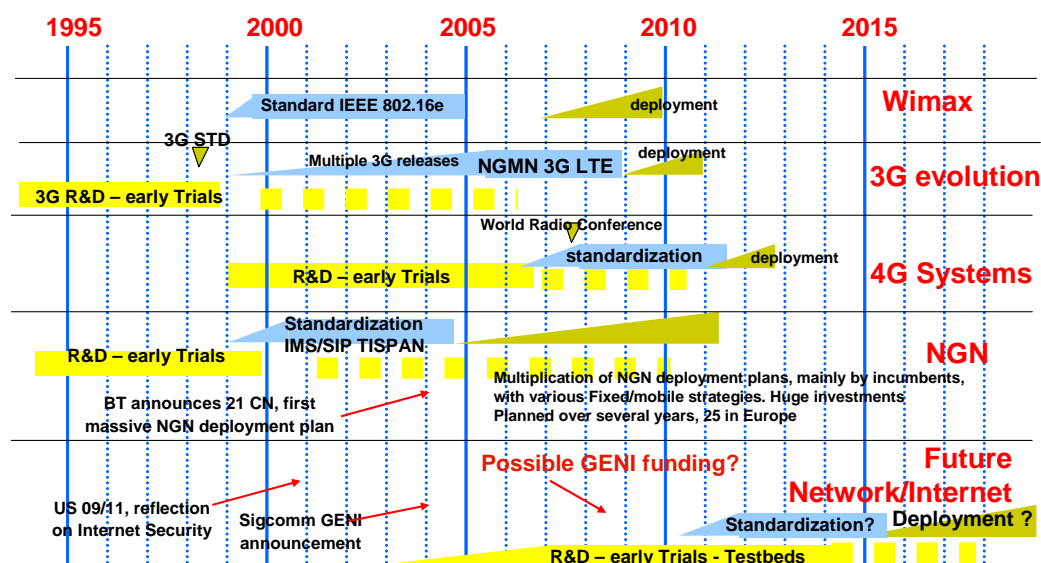


Figure 21: B3G/4G/B4G Migration Path and Key Challenges [49]

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Appendix

This appendix is including several characteristics and performances for the radio access technologies described in Chapter 1. Important information of different foras and groups has been used to make Chapter 1 the most complete as possible. The information in this Appendix are comparative tables for wireless and mobile communications, using different data, like frequency, throughput, data rate, etc.

Information of Non Licensed Frequency Technologies

Protocol	Release Date	Op. Frequency	Throughput (Typ)	Data Rate (Max)	Range (Indoor)	Range (Outdoor)
.11 Legacy	1997	2.4-2.5 GHz	0.7 Mbit/s	2 Mbit/s	~Depends on walls	~75 meters
.11a	1999	5.15-5.25/5.25-5.35/5.745-5.825 GHz	23 Mbit/s	54 Mbit/s	~30 meters	~100 meters
.11b	1999	2.4-2.5 GHz	4 Mbit/s	11 Mbit/s	~35 meters	~110 meters
.11g	2003	2.4-2.5 GHz	19 Mbit/s	54 Mbit/s	~35 meters	~110 meters
.11n	2007 (TGn draft 2.0) ratification timeline pushed to late 2008.	2.4 GHz and/or 5 GHz	74 Mbit/s	248 Mbit/s = 2x2 ant	~70 meters	~160 meters
UWB	2002 (FCC R&O)	3.1-10.6 GHz	100-500 Mbit/s (high data rate) 50-1000 kbit/s (low data rate)	50 Gbit/s (using the whole 7.5 GHz bandwidth)	~20 meters	~100 meters
Zigbee	1 st release - 2004 2 nd release - 2007	868MHz (EU), 915MHz (US), 2.4GHz (worldwide)	2-10kbps@868MHz 4-20kbps@915MHz - 25110kbps@2.4GHz (per channel)	20kbps@868MHz 40kbps@915MHz 250kbps@2.4GHz (per channel)	~20 meters	~75 meters

General information of NLF technologies

Technology	Cost	Coverage	User penetration	Broadband
UWB	10 USD (integrated circuit)	100 meters	N/A	YES
Zigbee	1 USD (Zigbee transceiver), 3USD (one radio, processor, memory package)	10-75 meters, depending on environment	Incipient	NO

General information of UWB and Zigbee

Frequency		RFID Range
Low-frequency	125-148 kHz	1m
High-frequency	13.56 MHz	1m
Ultra-high frequency	915 MHz	<10m
Microwave	2.45 GHz	<30m

General information of RFID

Comparison tables of Mobile Internet Access Methods

Comparison of Mobile Internet Access methods ¹						
Standard	Family	Primary Use	Radio Tech	Downlink (Mbps)	Uplink (Mbps)	Notes
802.16e	WiMAX	Mobile Internet	MIMO-SOFDMA	70	70	Quoted speeds only achievable at very short ranges, more practically 10 Mbps at 10 km.
HIPERMAN	HIPERMAN	Mobile Internet	OFDM	56.9	56.9	
WiBro	WiBro	Mobile Internet	OFDMA	50	50	Mobile range (900 m)
iBurst	iBurst 802.20	Mobile Internet	HC-SDMA	64	64	3-12 km
UMTS W-CDMA HSDPA + HSUPA	UMTS/3GSM	Mobile phone	CDMA/FDD	.384 14.4	.384 5.76	HSDPA widely deployed . Typical downlink rates today 1-2Mbps, ~200kbps uplink; future downlink up to 28.8Mbps .
UMTS-TDD	UMTS/3GSM	Mobile Internet	CDMA/TDD	16	16	Reported speeds according to IPWireless using 16QAM modulation similar to HSDPA+HSUPA
LTE UMTS	UMTS/4GSM	General 4G	OFDMA/MIMO/SC-FDMA (HSOPA)	>100	>50	Still in development
1xRTT	CDMA2000	Mobile phone	CDMA	0.144	0.144	Obsoleted by EV-DO
EV-DO 1x Rev. 0 EV-DO 1x Rev.A EV-DO Rev.B	CDMA2000	Mobile Internet	CDMA/FDD	2.45 3.1 4.9xN	0.15 1.8 1.8xN	Rev B note: N is the number of 1.25 MHz chunks of spectrum used. Not yet deployed.

Comparison of Mobile Internet Access Methods

¹ All speeds are theoretical maximums and will vary by a number of factors, including the use of external antennae, distance from the tower and the ground speed (i.e. communications on a train may be poorer than when standing still.) Usually the bandwidth is shared between several terminals. The performance of each technology is determined by a number of constraints, including the [spectral efficiency](#) of the technology, the cell sizes used, and the amount of spectrum available. For more information, see [Comparison of wireless data standards](#)

Characteristics	WLAN 802.11x	WiMAX 802.16e *	3GPP LTE	3GPP2 AIE	FLAIR/WINNER
Max. Peak Data Rate (Mbps)	300	128	100	200	1000
Channel Bandwidth (MHz)	20	1.25 to 20	1.25 to 20	1.25 to 20	1.25 to 100
Spectrum Band (GHz)	2.4 / 5.8	2 to 6	2	2	2 to 6
Access method	OFDMA	OFDMA	OFDMA SC-FDMA	OFDMA CDMA	flexible
Duplex mode		FDD, TDD	FDD, TDD	FDD, TDD	FDD, TDD
Mobility	low	low/mid	high	high	high
Relaying	partly integrated	partly integrated	not integrated	not integrated	integrated
Self configurability	partially supported	potentially supported	not supported	not supported	supported
Inter RAT compatibility	no	no	cooperative RRM	cooperative RRM	cooperative RRM
Domain	Local Area	Metropolitan Area (Wide Area)	Wide Area (Metropolitan Area)	Wide Area (Metropolitan Area)	Wide Area, Metropolitan Area, Local Area

Comparison of Mobile Internet Access Methods

Throughput (Mbit/s)				
Standard	Max Downlink	Max Uplink	Range	Typical Downlink
CDMA RTT 1x	0.307	0.153	~ 18 mi	0.125
CDMA EV-DO Rev. 0	2.458	0.153	~ 18 mi	0.75
CDMA EV-DO Rev. A	3.100	1.800	~ 18 mi	
CDMA EV-DO Rev. B	4.900	1.800	~ 18 mi	
GSM GPRS	0.080	0.040	~ 16 mi	0.014
GSM EDGE	0.474	0.474	~ 16 mi	0.034
UMTS W-CDMA R99	0.384	0.384	~ 18 mi	0.195
UMTS W-CDMA HSDPA	14.400	0.384	~ 18 mi	0.75 (Cingular 2006)
UMTS W-CDMA HSUPA	14.400	5.760		
UMTS-TDD	16 ^[1]	16		
UMTS HSOPA	100 ^[2]	50	(experimental)	
WiMAX: 802.16e	70	70	~ 4 mi	>10
WiFi: 802.11a	54	54		
WiFi: 802.11b	11	11	~ 30 meters	2
WiFi: 802.11g	54	54	~ 30 meters	10
WiFi: 802.11n	200	200	~ 50 meters	40

Throughput Table

Notes

- **Downlink** is the throughput from the base station to the user handset or computer.
- **Uplink** is the throughput from the user handset or computer to the base station.
- **Range** is the maximum range possible to receive data at 25% of the typical rate.
- HSOPA requires 20 MHz for 100 Mbit/s rate, 40 Mbit/s is available with 5 MHz

Allocated Frequencies		
Standard	Frequencies	Spectrum Type
UMTS over W-CDMA	850 MHz, 1.9, 1.9/2.1, and 1.7/2.1 GHz	Licensed (Cellular/PCS/3G/AWS)
UMTS-TDD	450, 850 MHz, 1.9, 2, 2.5, and 3.5 GHz ^[3] 2 GHz	Licensed (Cellular, 3G TDD, BRS/IMT-ext, FWA) Unlicensed (see note)
CDMA2000 (inc. EV-DO, 1xRTT)	450, 850, 900 MHz 1.7, 1.8, 1.9, and 2.1 GHz	Licensed (Cellular/PCS/3G/AWS)
EDGE/GPRS	850 MHz 900 MHz 1.8 GHz 1.9 GHz	Licensed (Cellular/PCS/PCN)
802.16e	2.3, 2.5, 3.5, 3.7 and 5.8 GHz	Licensed
802.11a	5.25, 5.6 and 5.8 GHz	Unlicensed 802.11a and ISM
802.11b/g/n	2.4 GHz	Unlicensed ISM
Bluetooth	2.4 GHz	Unlicensed ISM
Wibree	2.4 GHz	Unlicensed ISM
ZigBee	868 MHz, 915 MHz, 2.4 GHz	Unlicensed ISM
Wireless USB, UWB	3.1 to 10.6 GHz	Unlicensed Ultrawideband
EnOcean	868.3 MHz	Unlicensed ISM

Frequency Table

Notes

- Where X/YxHz is used (eg 1.7/2.1 GHz), the first frequency is used for the uplink channels and the second for the downlink channels.
- Unlicensed frequencies vary in how they can be used. 802.11a can make use of both 802.11a-only spectrum and ISM spectrum around 5-6 GHz. A portion of the 2010 MHz spectrum is allocated to unlicensed UMTS-TDD in Europe, but cannot be used for other standards, whereas ISM bands can generally be used for any technology. This improved flexibility does have the downside that ISM bands are often over-used with incompatible, interfering, technologies.
- Unlicensed bands vary from country to country. Most have a 2.4 GHz ISM band, but other bands are only available in certain countries and non ISM bands have restrictions as noted above.
- In Europe, part of the 2 GHz 3G TDD band is designated as unlicensed, but where available is restricted to UMTS TDD operation.^[4] To date, this has been left unused and some jurisdictions are re-allocating it to licensed use only.
- AMPS/CDMA users tend to refer to 850 MHz band as 800 MHz, whereas 850 MHz is closer and is used by the GSM/UMTS community. For consistency, it is referred to here as 850 MHz.

Allocated Spectrum per Channel (MHz)				Spectral efficiency (Bits per second per Hz)		
Standard	Spectrum			Standard	Downlink	Uplink
	Total	Uplink	Downlink	802.16e	1.91	0.84
802.16e	10	Variable	Variable	EVDO 1x A	0.85	0.36
802.11a	20			EVDO 3x B	0.93	0.28
802.11b	20			HSDPA	0.78	0.14
802.11g	20			HSUPA	0.78	0.30
802.11n	20 or 40					
EVDO 1x A	2.4	1.25	1.25			
EVDO 3x B	10	5	5			
UMTS (W-CDMA)	10	5	5			

Allocated Spectrum per Channel and Spectral Efficiency

Source: http://en.wikipedia.org/wiki/Comparison_of_wireless_data_standards