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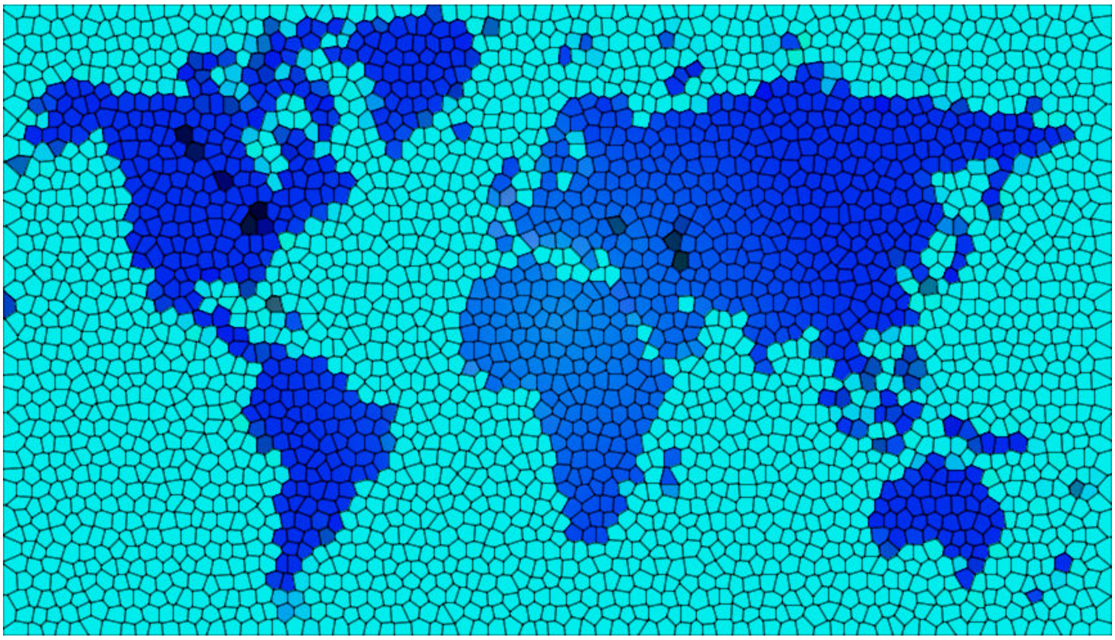

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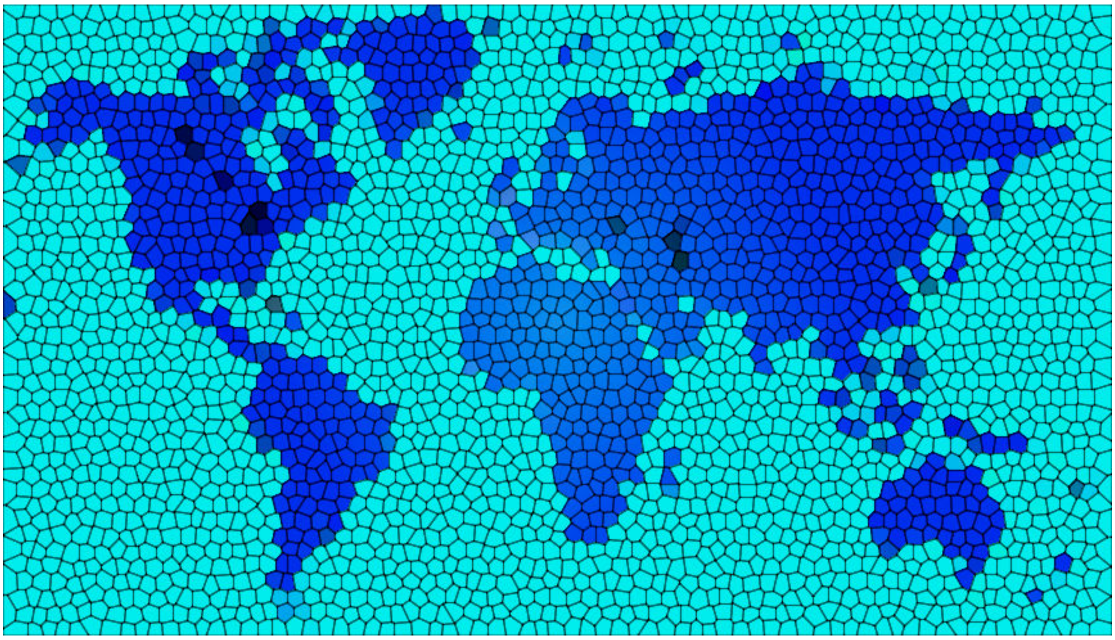
"Αλληλεπίδραση των 2G, 3G & 4G Ασύρματων Δικτύων"



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Abstract

Mobile communications are conducted through various standards and technologies, and they are grouped by the level of their evolution into five generations. The beginning was the analog generation and now researchers are working on the 4th Generation Wireless Networks. The purpose of this document is to present an overview of every generation, how these generations interwork and how the Wireless Networks will be in the future. In particular, in chapter 2 we examine AMPS Networks, 2G, 2.5G, 3G, 4G Wireless Networks and how an operator can move from one generation to the other. In chapter 3 we present some statistical data about the recent worldwide situation, which countries have launched certain wireless technologies and what kind of technologies these are. In chapter 4 we examine the interworking issues between 2G and 3G Networks and more specifically between GSM and UMTS on one hand and CDMAOne and CDMA2000 on the other. In chapter 5 we introduce the interworking issues between 3G and 4G Networks. In chapter 6 we complete this document with an overview of the contemporary situation throughout the world and how it this situation is expected to evolve in the future.

Περίληψη

Τα δίκτυα κινητής τηλεφωνίας πραγματοποιούνται μέσω διαφόρων προτύπων και τεχνολογιών και ομαδοποιούνται ανάλογα με το επίπεδο εξέλιξης του σε τέσσερις γενιές (συν μία ενδιάμεση την 2.5G). Στην αρχή εμφανίστηκε η αναλογική γενιά και μετά από μια ραγδαία εξέλιξη τώρα οι μελετητές εργάζονται για την τέταρτη γενιά των ασύρματων αυτών δικτύων. Ο σκοπός αυτού του εγγράφου είναι να παρουσιάσει μια γενική εικόνα της κάθε γενιάς, πως αυτές οι γενιές αλληλεπιδρούν και πως θα είναι τα ασύρματα δίκτυα κινητής τηλεφωνίας στο μέλλον. Πιο συγκεκριμένα στο κεφάλαιο 2 μελετούμε τα AMPS δίκτυα, τα δίκτυα δεύτερης, δυόμισι, τρίτης και τέταρτης γενιάς και πως μπορεί ένας διαχειριστής δικτύου να μεταβεί από την μια γενιά στην άλλη. Στο κεφάλαιο 3 παρουσιάζουμε κάποια στατιστικά δεδομένα για την σημερινή κατάσταση στο κόσμο, ποιες χώρες έχουν ξεκινήσει την εφαρμογή δικτύων κινητής τηλεφωνίας και τι είδους δίκτυα είναι αυτά. Στο κεφάλαιο 4 παραθέτουμε όλα τα ζητήματα που αφορούν στην αλληλεπίδραση μεταξύ των 2G και 3G δικτύων, και πιο συγκεκριμένα των GSM και UMTS από την μία και των CDMAOne και CDMA2000 από την άλλη. Στο κεφάλαιο 5 παρουσιάζουμε τα ζητήματα που αφορούν την αλληλεπίδραση των 3G και 4G δικτύων. Τέλος στο κεφάλαιο 6 ολοκληρώνουμε το παρών έγγραφο με μια ανασκόπηση της σημερινής κατάστασης που επικρατεί στο κόσμο και πως αναμένεται αυτή η κατάσταση να εξελιχθεί στο μέλλον.

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1 Introduction

Mobile communications development is nowadays at a turning point. Global cellular subscribers increase with a rapid pace (Figure 1) and they have reached such an amount that indicates how important and helpful the use of the mobile technology is. New services and technologies are being introduced to the public and to modern enterprise; customer expectations are growing and competition amongst operators and amongst service providers are intensifying. The Internet has already evolved into a real information superhighway and the need to reach this information on the way is gradually becoming more immense.

Wireless services are also proliferating, while companies are starting to make way for freedom that data networking and telecommunications offers their customers, partners and employees. Simultaneously, telecommuting, videoconferencing, voice mail, paging, e-mail, cellular phones, personal digital assistants (PDA's) and laptops enable professionals to conduct business anywhere and at any time.

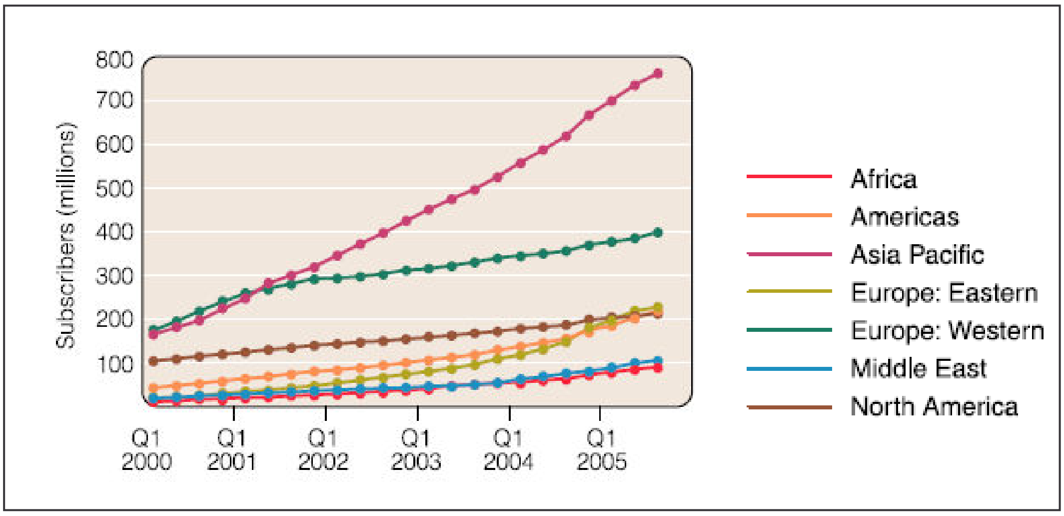

Figure 1: Global cellular subscribers by region [7]

Keeping abreast of new research and industry trends is key in developing a good strategy that is compatible with the fast pace of the information technology industry. When faced with making decisions, engineers need to be aware of current and emerging trends of the communications world. Many new ideas are not only creative and innovative but technically challenging as well. This calls for a very good system perspective and detailed knowledge in a number of key areas.

In the following sections we will try to examine all the Cellular Wireless Technologies of the past, present and the future and focus on the interworking between the 2nd, 3rd and 4th generations of Wireless Networks. Each generation uses different standards and that causes some problems when an operator wants to evolve its network and services. We present in this document all the up-coming barriers and difficulties for this evolution, what do the statistical data indicate for the current worldwide situation and what the future developments will bring.

2 From the AMPS to the 4G Wireless Networks

In this section of the document we are going to examine all the Cellular Networks standards beginning with the first analog systems, then the 2G, 2.5G, 3G and 4G Wireless Networks. We are going to give a more extensive presentation of the GSM standard of the second generation, because it is the world's most popular technology and it will help us understand how all the Cellular Networks work. Finally at the end of this section we are going to gather all these standards and present all the different paths that the operators can take in order to evolve their networks from one technology to the next.

2.1 *AMPS - Analog Mobile Phone Systems*

The first generation of wireless mobile communications was based on analog signaling. Analog systems, implemented in North America, were known as Analog Mobile Phone Systems (AMPS), while systems implemented in Europe and the rest of the world, were typically identified as a variation of Total Access Communication Systems (TACS). Analog systems were primarily based on circuit-switched technology and designed for voice, not data. [3]

2.2 *2G – 2nd Generation Wireless Technology*

2G stands for 2nd generation and it refers to the second-generation wireless technology. The dominant wireless-networking technology at the time of writing this document has been 2G technology, which is digital, circuit-based, and narrowband (200-KHz-wide carrier) but suitable for voice and limited data communications. Technologies used in 2G communications include GSM, IS-95 (commonly known As CDMAOne), IS-136 (commonly known as D-AMPS) and PDC. We will now examine each one of these technologies.

GSM

GSM stands for Global System for Mobile Communications and it is the world’s most popular 2G technology, implemented in most of Europe and Asia. Like TDMA

(Time Division Multiple Access), it is based on time-division multiplexing but uses wider carrier frequencies and eight, rather than three, time slots. [1]

GSM phones are used by over a billion people across more than 200 countries. The ubiquity of the GSM standard makes international roaming very common with "roaming agreements" between mobile phone operators. GSM differs significantly from its predecessors in that both signalling and speech channels are digital, which means that it is seen as a second generation (2G) mobile phone system.

From the point of view of the consumer, the key advantage of GSM systems has been early delivery of new services at low costs. For example text messaging was developed first for GSM. The advantage for network operators has been the low infrastructure cost which is caused by open competition. The primary disadvantage has been that GSM's radio network is based on TDMA technology, which is considered less advanced than competing CDMA-based systems. Practical performance figures are rather similar; however, GSM has retained backward-compatibility with the original GSM phones. [2]

History

In spite of the current popularity, the history of mobile phones began long before GSM was conceived. The GSM group ("Groupe Special Mobile" (French) 1, 2, 3 and 4) was founded in 1982. The name of the system comes from the name of this group, though later the decision was made to keep the initials but to change what they stood for. Originally the group was hosted by CEPT. The European Conference of Postal and Telecommunications Administrations (CEPT) was established on June 26, 1959 as a coordinating body for European state telecommunications and postal organizations. The acronym comes from the French version of its name.

The technical fundamentals of the GSM system were defined in 1987. In 1989, ETSI (CEPT's offspring) took over control and by 1990 the first GSM specification was completed and came to over 6,000 pages of text. Commercial operation began in 1991 with Radiolinja in Finland. In 1998, the 3rd Generation Partnership Project (3GPP) was formed. Originally it was intended only to produce the specifications of the next (third, 3G) generation of mobile networks. However, 3GPP also took over the maintenance and development of the GSM specification. [2]

Market situation

More than one billion people use GSM phones as of 2004, making GSM the dominant mobile phone system worldwide with about 70% of the worlds market. GSM's main competitor, CDMA2000, is used primarily in the United States, although it was seeing increased, but limited, worldwide adoption as a stepping stone to a 3G standard when WCDMA did not appear to be fully functional. As WCDMA networks have begun to take off, at least in high density markets, GSM's rate of expansion may slow, this seems likely to take some time, however. A major reason for the growth in GSM usage, particularly between 1998 and 2002, was the availability of prepaid calling from mobile phone operators. This allowed people to have mobile phones who were either unable or unwilling to enter into an ongoing contract with the operator. [2]

In Figures 2 and 3 we can see the GSM coverage worldwide and in Greece respectively.

Figure 2: World GSM coverage (September 2005) [7]

Figure 3: GSM coverage by Cosmote - Greece (2005) [9]

Radio interface

GSM employs TDMA between stations on a frequency duplex pair of radio channels, with slow frequency hopping between channels. GSM also uses SDMA (Space-Division Multiple Access is a channel access method which enables the use of the same frequency at the same time in different spaces (cells). This means, however, the cells can't be next to each other. Cells using the same frequency are typically separated by two cells.) and FDMA (In Frequency-Division Multiple Access, each transmitter is assigned a distinct frequency channel so that receivers can discriminate among them by tuning to the desired channel.). It uses a modified Gaussian shift-key modulation. This modulation scheme inherently gives mobile units better battery life because it encodes the data by varying the frequency of the signal, not the amplitude. This allows amplifiers to be run at high power levels without distorting the transmitted data (good power efficiency). However, the trade-off is that each user consumes more bandwidth, which means that more spectrum is necessary to serve the same number of users than with other modulation schemes (poor spectral efficiency). GSM networks operate at various GSM frequency ranges.

The GSM network consists of cells and cells can be named after their size. Basically there are 4 different cell sizes - Macro, micro, pico and umbrella-cells. The coverage area of each cell is different in different environments (Figure 4). Macro cells can be regarded as cells where the base station antenna is installed in a mast or a building above the average roof top level. However, micro cells are cells where the antenna height is under the average roof top level and they are typically used in urban areas. The pico-cells are small cells whose diameter is a few dozen metres and are mainly used indoors. On the other hand, umbrella-cells are used to cover shadow regions of smaller cells and fill in gaps in coverage between those cells. These cells are usually built on top of tall buildings or in other high places.

The cell radius can vary depending on the antenna height, antenna gain and propagation conditions from couple of hundred meters to several tens of kilometres. Because of the timeslot (time period allocated to one call) overlap that occurs when mobile phones are a large distance away from a base station, 35 km is the longest distance the GSM specification supports in practical use. The specification does define an extended cell, where the cell radius could be double or even more. This is done by utilizing 2 timeslots per user, so the call has a better chance of hitting the right timeslot. Indoor coverage is also supported by GSM.

Indoor coverage can be built by using power splitters to deliver an RF (Radio Frequency) signal from the antenna outdoors to a separate indoor antenna distribution system. When all the capacity of the cell is needed indoors, as in shopping centres or airports, indoor coverage can be built by using antennas only inside the building. In suburban areas the indoor coverage is usually provided by in-building penetration of the radio signal, not by a separate indoor antenna system. [2]

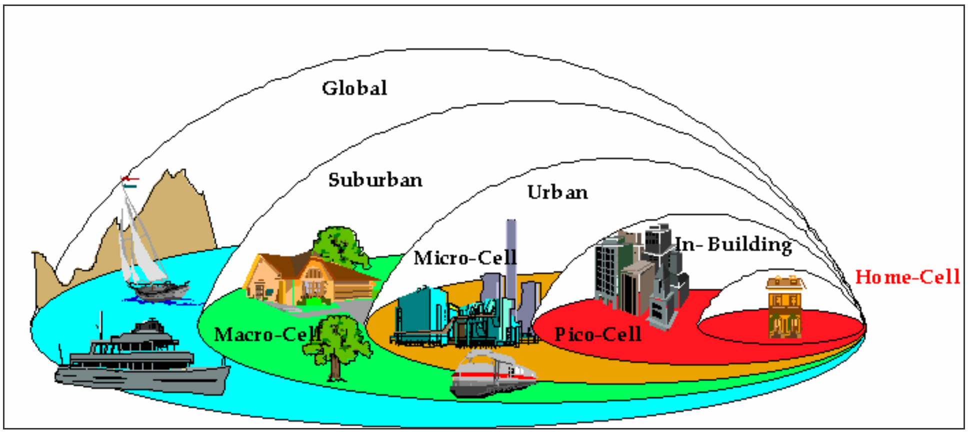

Figure 4: Different cell coverage areas [10]

Network structure

The network behind the GSM system (Figure 5) seen by the customer is large and complicated in order to provide all of the services which are required. It is divided into a number of sections and these are each covered in separate articles.

- The Base Station Subsystem (the base stations and their controllers).
- The Network and Switching Subsystem (the part of the network most similar to a fixed network). This is sometimes also just called the core network.
- The GPRS Core Network (the optional part which allows packet based Internet connections).
- All of the elements in the system combine to produce many GSM services such as voice calls and SMS that are available to subscribers. [2]

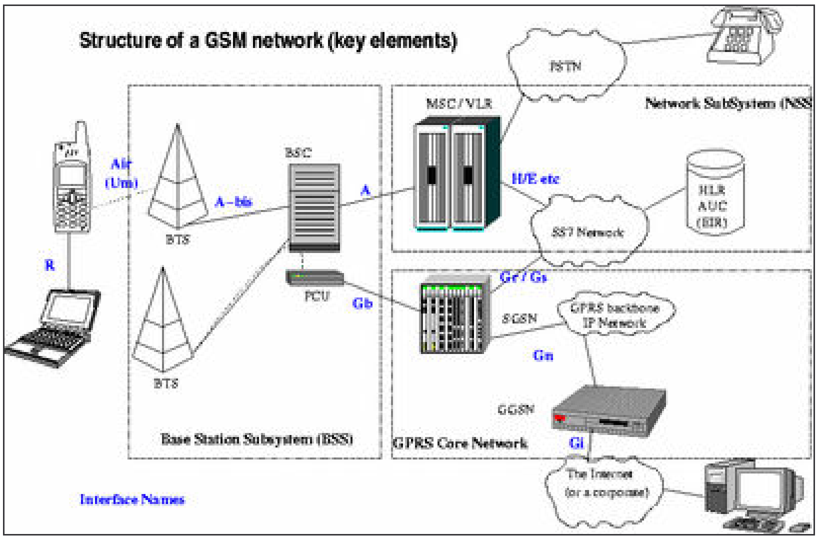

Figure 5: The structure of a GSM network [2]

Subscriber Identity Module (SIM)

One of the key features of GSM is the Subscriber Identity Module (SIM), commonly known as a SIM card. The SIM is a detachable smartcard containing the user's subscription information and phonebook. This allows the user to retain his information while switching handsets. Alternatively, the user can also change operators while retaining the handset simply by changing the SIM. Some operators will block this by allowing the phone to use only a single SIM, or only a SIM issued by them; this practice is known as SIM locking, and is illegal in some countries. In the USA most operators do lock the mobiles they sell. This is done because the price of the mobile phone is usually subsidised with revenue from subscriptions and operators want to try to avoid subsidising competitor's mobiles. [2]

Figure 6: SIM card [14]

A subscriber can usually contact the provider to remove the lock for a fee (which operators sometimes try to claim to be ignorant of), utilize private services to remove the lock, or make use of ample software and websites available on the Internet to unlock the handset themselves. Some providers in the USA, such as T-Mobile, will unlock the phone for free if the customer has held an account for a certain period. In most countries removing the lock is not illegal. [2]

GSM security

GSM was designed with a moderate level of security. The system was designed to authenticate the subscriber using shared-secret cryptography. Communications between the subscriber and the base station can be encrypted. GSM uses several cryptographic algorithms for security. The A5/1 and A5/2 stream ciphers are used for ensuring over-the-air voice privacy. A5/1 is a stronger algorithm used within Europe; A5/2 is weaker and used in other countries. Serious weaknesses have been found in both algorithms, and it is possible to break A5/2 in real-time in a cipher text-only attack. The system supports multiple algorithms so operators may replace that cipher with a stronger one. [2]

IS-95 (CDMAOne)

Interim Standard 95 (IS-95) is the first CDMA-based digital cellular standard pioneered by Qualcomm. The brand name for IS-95 is CDMAOne. IS-95 is also known as TIA-EIA-95. It is a 2G mobile telecommunications standard that uses CDMA, a multiple access scheme for digital radio, to send voice, data and signaling data (such as a dialed telephone number) between mobile telephones and cell sites.

CDMA or "code division multiple access" is a digital radio system that transmits streams of bits. CDMA permits several radios to share the same frequencies. Unlike TDMA "time division multiple access", a competing system used in GSM, all radios can be active all the time, because network capacity does not directly limit the number of active radios. Since larger numbers of phones can be served by smaller numbers of cell-sites, CDMA-based standards have a significant economic advantage over TDMA-based standards, or the oldest cellular standards that used frequency-division multiplexing.

It is used in the USA, South Korea, Canada, Mexico, Israel, Australia, Venezuela and China. [12] CDMA will eventually be replaced with 2.5G and 3G technology such as CDMA2000 1zRTT, CDMA2000 1xEVDO, WCDMA, and I-CDMA. [1] We will examine most of these technologies later on this document.

IS-136 (D-AMPS)

IS-136 is a second-generation (2G) mobile phone system also called D-AMPS. It is now mostly being superseded by GSM systems, but even in its heyday was primarily used only in the Americas, particularly the USA. IS-136 was designed as a digital extension to the advanced mobile phone system (AMPS). IS-54 was an earlier version of D-AMPS which used the same timeslot structure and encryption, but lacked some extra features.

D-AMPS was designed to use existing AMPS channels and allow a smooth transition since both systems could co-exist in the same area. IS-54 increased capacity over the preceding analogue design by dividing each 30 kHz channel pair into three time slots (using TDMA technology) and digitally compressing the voice data, yielding three times the call capacity at some expense of voice quality. Moving to a digital system also made calls more secure because analogue scanners could not access digital signals, and new scanners in the U.S. were prohibited by the FCC (Federal Communications Commission) from accessing cell-phone frequencies. Calls were also encrypted, although the algorithm used, CMEA (Cellular Message Encryption Algorithm) was later found to be weak.

IS-136 superseded IS-54, a previous extension to AMPS, adding features such as text messaging and data capabilities borrowed from competing GSM and IS-95/CdmaOne standards. IS-136 is used primarily by Cingular Wireless, AT&T Wireless, and US Cellular. Cingular (who has purchased AT&T Wireless in October 2004) is now migrating to an all GSM network. At the same time, US Cellular is migrating to an all CDMA network. [2]

PDC

Personal Digital Cellular (PDC) is a 2G mobile phone standard developed and used exclusively in Japan. Like D-AMPS and GSM, PDC uses TDMA. NTT

DoCoMo launched PDC's service in March 1993. PDC is implemented in the 800 MHz and 1.5 GHz bands.

The services include voice (full and half-rate), supplementary services (call waiting, voice mail, three-way calling, call forwarding, and so on), data service (up to 9.6 kb/s CSD), and packet-switched wireless data (up to 28.8 kb/s PDC-P).

PDC has 61.817 million subscribers as of end December 2003 but is slowly being phased out in favor of 3G technologies like W-CDMA and CDMA2000. [2]

2.3 *2.5G – 2.5 Generation Wireless Technology*

2.5G Wireless technology is a technology bridge between second-generation (2G), and third-generation (3G) wireless cellular technologies. The term "second and a half generation" is used to describe systems that provide faster services than 2G, but not quite as fast or advanced as newer 3G systems. [2]

Researchers developed 2.5-generation technologies as upgrades to 2G approaches. 2.5G has more bandwidth than 2G but less than 3G. 2.5G uses existing 2G spectra and doesn't require an entirely new network infrastructure. Thus it can be implemented faster and less expensively than 3G. 2.5G approaches include high-speed circuit-switched data (HSCSD) technology, a GSM extension that offers throughput of up to 38.4 Kbits per second. 2.5G also uses iDEN, GPRS, and EDGE upgrade technologies.

HSCSD

High Speed Circuit Switched Data (HSCSD) is an enhancement of data services ("Circuit Switched Data - CSD) over all GSM (2G) networks. It allows you to access non-voice services at 3 or more times the rate normally associated with 2G, which means subscribers are able to send and receive data from their portable computers at a speed of up to 43.2 kbps on fully deployed networks. The HSCSD solution enables higher rates by using multiple channels, allowing subscribers to enjoy faster rates for their Internet, e-mail, calendar and file transfer services.

iDEN

Integrated Digital Enhanced Network: Motorola developed iDEN, a GSM (2.5G) upgrade that uses enhanced compression and modulation technologies to deliver data rates of 64Kbits per second. iDEN is currently used in most of North America and South America, as well as in China and Japan.

GPRS

General Packet Radio Service (GPRS) is a 2.5G digital cellular phone standard for data speeds up to 171 Kbps. This is an upgrade for GSM networks. GPRS reallocates several GSM time slots from voice to data uses, thereby increasing data rates but decreasing voice rates. GPRS services have recently been rolled out in various locations principally in China, Europe, and the US.

EDGE

Enhanced Data GSM Environment (EDGE) is a wireless digital cellular technology. Specifically a 2.5G GSM upgrade, designed to provide data rates up to 384 Kbits per second. EDGE was initially developed by Ericsson and scheduled for commercial use this year, uses 3G transmission technology but works in GSM's (2.5G) frequency range. In addition EDGE works with new modulation and radio techniques that use existing frequency more efficiently. [1]

2.4 3G – 3rd Generation Wireless Technology

3G is short for third-generation mobile telephone technology. The services associated with 3G provide the ability to transfer both voice data (a telephone call) and non-voice data (such as downloading information, exchanging email, and instant messaging). 3G was supposed to be a single, unified, worldwide standard, but in practice, the 3G world has been split into three camps:

UMTS (W-CDMA)

UMTS (Universal Mobile Telephone System), based on W-CDMA technology, is the solution generally preferred by countries that used GSM, centered in Europe. UMTS is managed by the 3GPP organization also responsible for GSM, GPRS and EDGE. [2]

Building on current investments in GSM/GPRS, 3G/UMTS offers mobile operators significant capacity and broadband capabilities to support greater numbers of voice and data customers – especially in urban centres – plus higher data rates at lower incremental cost than 2G.

Making use of radio spectrum in bands identified by the ITU for Third Generation IMT-2000 mobile services and subsequently licensed to operators, 3G/UMTS uses a 5 MHz channel carrier width to deliver significantly higher data rates and increased capacity compared with second generation networks. This 5 MHz channel carrier provides optimum use of radio resources, especially for operators who have been granted large, contiguous blocks of spectrum – typically ranging from 2x10 MHz up to 2x20 MHz – to reduce the cost of deploying 3G networks.

Crucially, 3G/UMTS has been specified as an integrated solution for mobile voice and data with wide area coverage. Universally standardised via the Third Generation Partnership Project and using globally harmonised spectrum in paired and unpaired bands, 3G/UMTS in its initial phase offers theoretical bit rates of up to 384 kbps in high mobility situations, rising as high as 2 Mbps in stationary/nomadic user environments. Symmetry between uplink and downlink data rates when using paired (FDD - Frequency Division Duplexing) spectrum also means that 3G/UMTS is ideally suited for applications such as real-time video telephony – in contrast with other technologies such as ADSL where there is a pronounced asymmetry between uplink and downlink throughput rates. [13]

CDMA2000

The other significant 3G standard is CDMA2000, which is an outgrowth of the earlier 2G CDMA standard IS-95. CDMA2000's primary proponents are outside the GSM zone in the Americas, Japan and Korea. [2]

CDMA2000 is managed by 3GPP2, which is separate and independent from UMTS's 3GPP. CDMA2000 represents a family of technologies that includes CDMA2000 1X and CDMA2000 1xEV.

- CDMA2000 1X can double the voice capacity of CDMAOne networks and delivers peak packet data speeds of 307 kbps in mobile environments.
- CDMA2000 1xEV includes:
    - CDMA2000 1xEV-DO that delivers peak data speeds of 2.4Mbps and supports applications such as MP3 transfers and video conferencing.

- CDMA2000 1xEV-DV that provides integrated voice and simultaneous high-speed packet data multimedia services at speeds of up to 3.09 Mbps.

1xEV-DO and 1xEV-DV are both backward compatible with CDMA2000 1X and CDMAOne.

The world's first 3G (CDMA2000 1X) commercial system was launched by SK Telecom (Korea) in October 2000. Since then, CDMA2000 1X has been deployed in Asia, North and South America and Europe, and the subscriber base is growing at 700,000 subscribers per day. CDMA2000 1xEV-DO was launched in 2002 by SK Telecom and KT Freetel. The commercial success of CDMA2000 has made the IMT-2000 vision a reality (International Mobile Telecommunications-2000 is the global standard for third generation (3G) wireless communications as defined by the International Telecommunication Union). [6] [2]

CDMA2000 benefited from the extensive experience acquired through several years of operation of CDMAOne systems. As a result, CDMA2000 is a very efficient and robust technology. Supporting both voice and data, the standard was devised and tested in various spectrum bands, including the new IMT-2000 allocations. [6]

- Increased Voice Capacity
- Higher Data Throughput
- Frequency Band Flexibility
- Increased Battery Life
- Synchronization
- Power Control
- Soft Hand-off
- Transmit Diversity
- Voice and Data Channels
- Traffic Channel
- Supplemental Channels
- Turbo Coding
- Connectivity to ANSI-41, GSM-MAP, and IP networks
- Full backward compatibility
- Improved service multiplexing and QoS management
- Flexible channel structure in support of multiple services with various QoS and variable transmission rates

TD-SCDMA

A less well known standard is TD-SCDMA which is being developed in the People's Republic of China by the companies Datang and Siemens. They are predicting an operational system for 2005. [2]

2.5 *4G – 4th Generation Wireless Technology*

4G is short for fourth-generation, the successor of 3G and is a wireless access technology. It describes two different but overlapping ideas:

- High-speed mobile wireless access with a very high data transmission speed, of the same order of magnitude as a local area network connection (10 Mbits/s and up). It has been used to describe wireless LAN technologies like Wi-Fi, as well as other potential successors of the current 3G mobile telephone standards.

- Pervasive networks. An amorphous and presently entirely hypothetical concept where the user can be simultaneously connected to several wireless access technologies and can seamlessly move between them. These access technologies can be Wi-Fi, UMTS, EDGE or any other future access technology. Included in this concept is also smart-radio technology to efficiently manage spectrum use and transmission power as well as the use of mesh-routing protocols to create a pervasive network. [2]

Figure 7 indicates that the future is based on the packet implementation of the systems and the circuit is step-by-step swept away.

	2G (2000)	Early 3G (2002/3)	Late 3G (2004/5)	4G (2006+)
Air Interface				
Voice	Circuit	Circuit	Circuit	Packet
Data	Circuit	Packet	Packet	Packet
Access Network				
Voice	Circuit	Circuit	Packet	Packet
Data	Circuit	Circuit	Packet	Packet
Core Network				
Voice	Circuit	Packet	Packet	Packet
Data	Overlay Packet	Packet	Packet	Packet

Figure 7: A packet based future [4]

2.6 *Different paths towards 4G*

Till now we examined a variety of standards and technologies that form the 2G, 2.5G, 3G and 4G technologies. In Figure 8 all these standards are gathered and it is depicted all the different paths that an operator can take in order to reach the third generation technology and beyond.

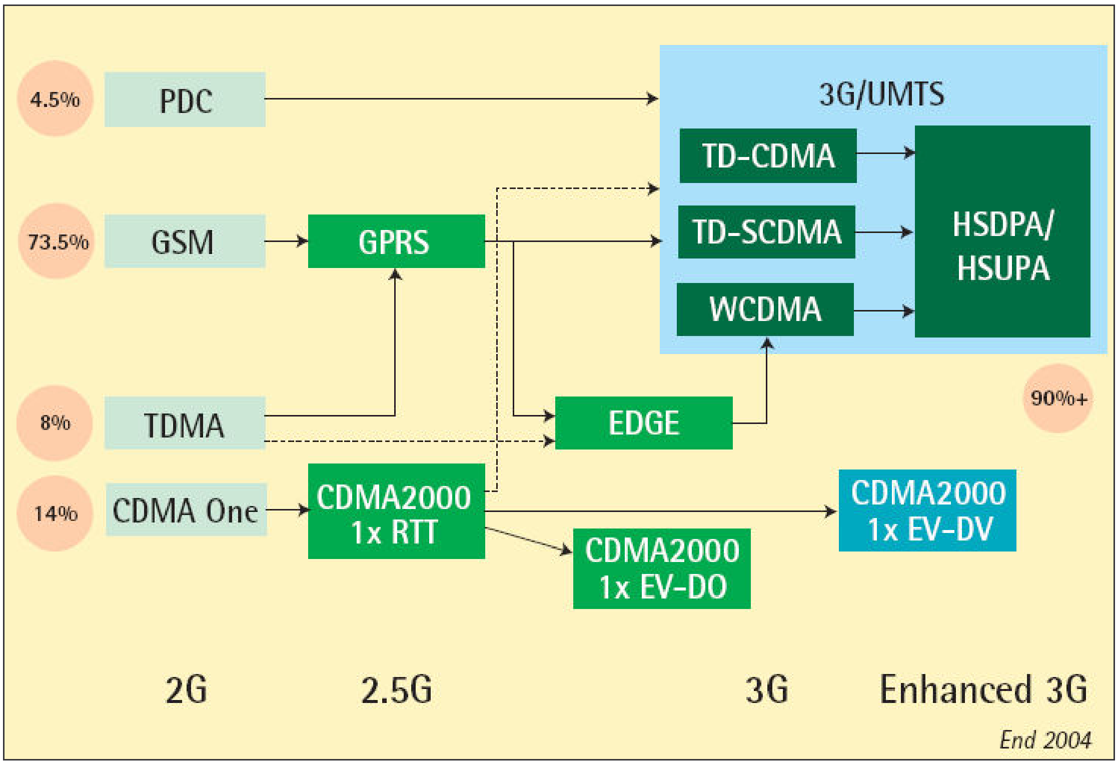

Figure 8: 3G operator evolution options [13]

3 Statistical Data

In the following figures it is depicted a variety of statistical data that present the current global situation, in regard with the Cellular Wireless Networks. Figure 9 shows the worldwide growth rate of the WCDMA and CDMA2000/EV-DO subscriptions from December 2003 to August 2005.

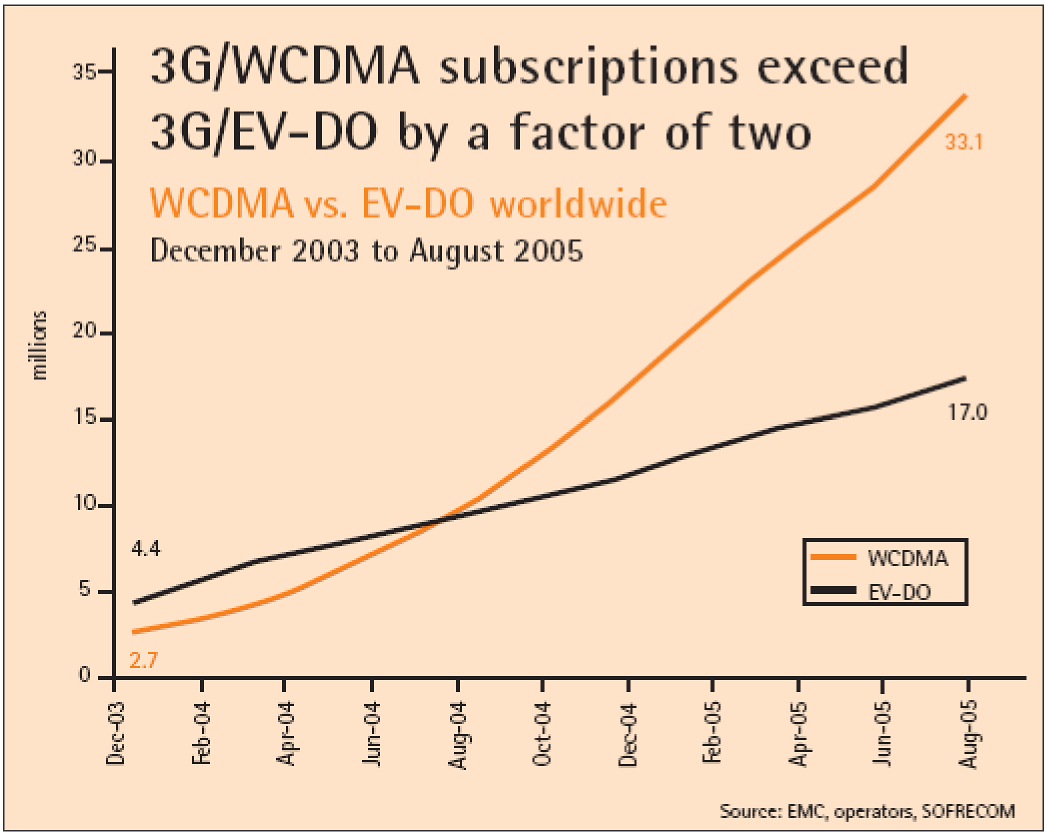

Figure 9: 3G subscriptions worldwide [13]

Figure 10 depicts the technology market shares that the different mobile standards have. It is obvious that GSM is the dominant standard, as it was mentioned before in this document. With the term CDMA, the graph refers to the CDMA-based standards, such as IS-95 and CDMA2000. With TDMA it refers to the IS-136 standard.

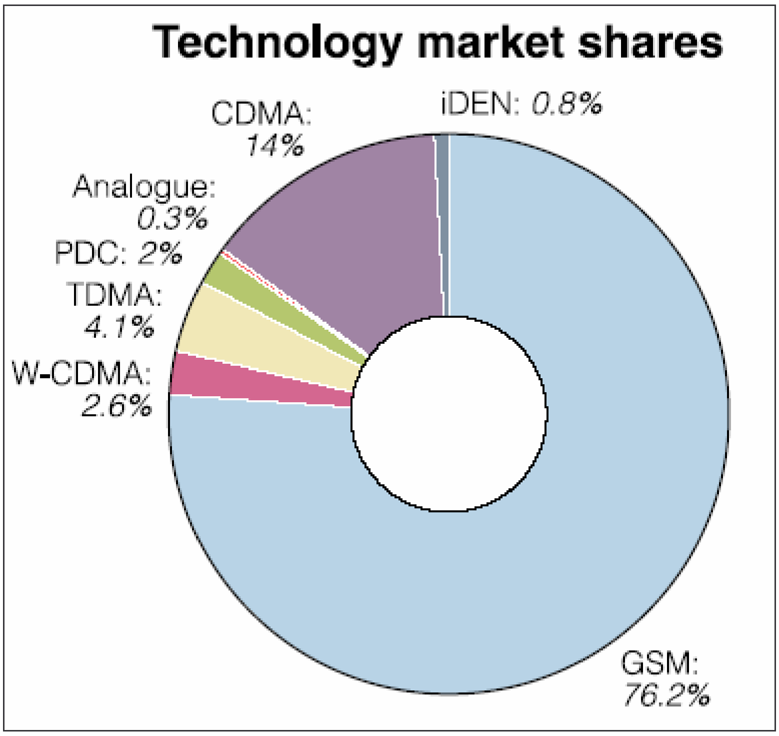

Figure 10: Technology market shares (September 2005) [7]

In Figure 11 we can see which European countries have launched any of the 3G technologies (WCDMA or EV-DO), a combination of 3G and EDGE standard, only EDGE standard or no standard at all. Figure 10 is a worldwide extension of Figure 9.

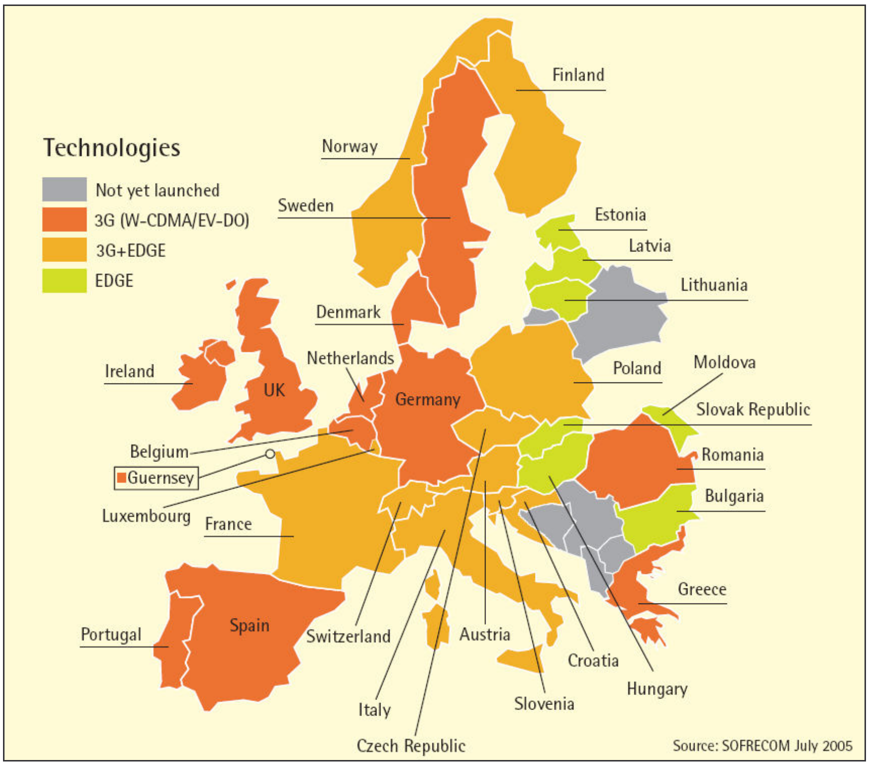

Figure 11: Launched technologies in Europe [13]

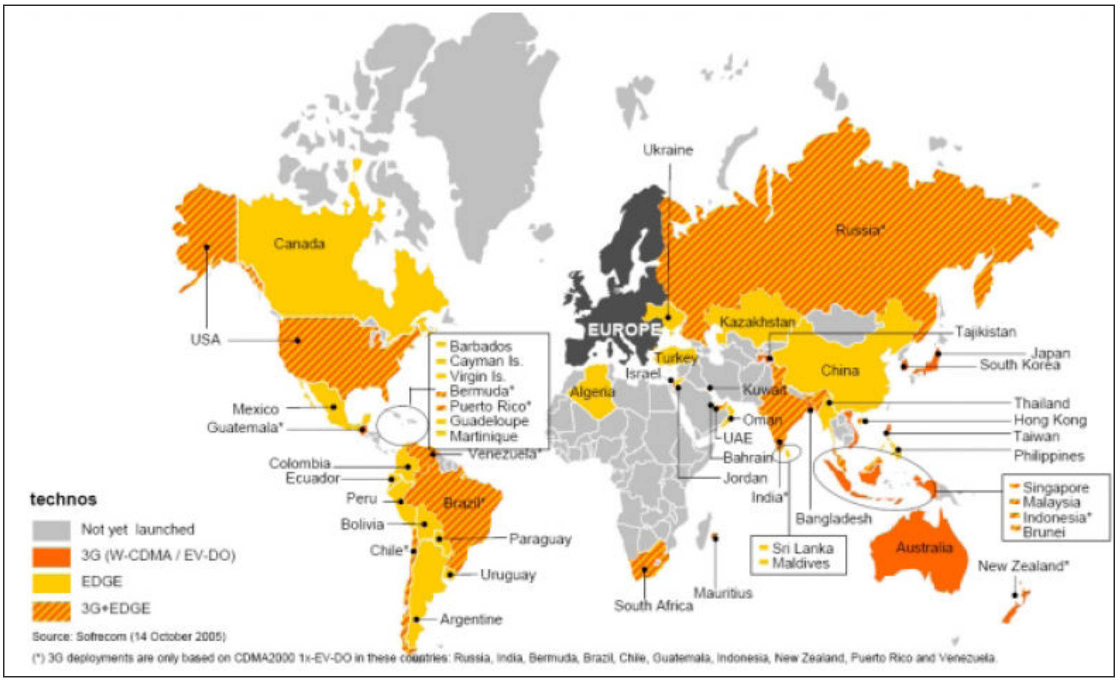

Figure 12: Launched technologies globally (Source: SOFRECOM October 2005) [13]

In the two previous figures we have seen in which countries are certain technologies launched and not the coverage areas of these technologies. 3G coverage is still limited to the urban areas and it covers much less space than 2G networks do. A very good example for this coverage difference is showed in Figure 13, where we can see with blue color the Germany's GSM (2G) coverage area (it covers almost the whole country) and with red color the UMTS (3G) coverage area (it covers only the areas around cities).

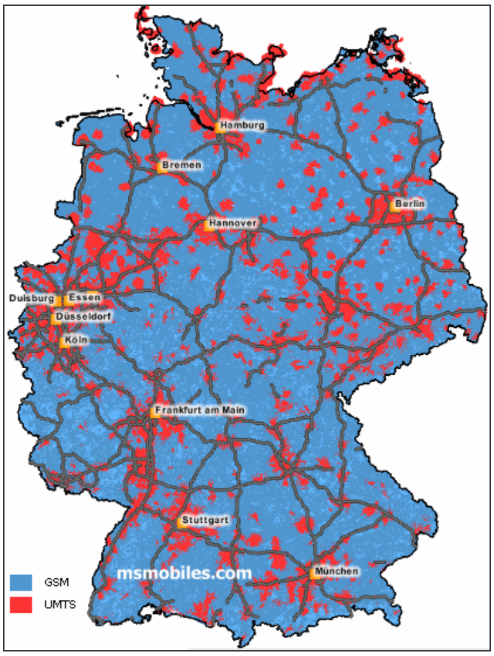

Figure 13: GSM and UMTS coverage in Germany (2004) [11]

4 Interworking of 2G and 3G

As we mentioned in the second chapter there are two main rivaling technologies in the world that implement 3G Networks, UMTS (WCDMA) and CDMA2000. In this section we are going to examine how an operator can evolve its network from GSM to UMTS and from CDMAOne to CDMA2000. We will examine all the barriers and problems that can show up and what actions have to be taken in order to have the most cost effective evolution, with the less effort needed.

4.1 *From GSM (2G) to UMTS (3G)*

Operators and UMTS networks

As of December 2003, the evolution of the 3G networks has been on its way for a couple of years now. The main reasons for these changes are basically the limited capacity of the existing 2G networks. The second generation of networks was built mainly for telephone calls and slow data transmission. Due to the rapid changes in technology, these factors do not meet the requirements of today's wireless revolution. The developments of so-called "2.5G" technologies such as HSCSD and GPRS have been ways of postponing the oncoming change to 3G networks, but are not permanent solutions. They are merely stepping stones towards the new technology. These stepping stones were built to introduce the possibilities on the future wireless application technology to the end consumers. These procedures are necessary to ensure that the operators and the infrastructure itself have a healthy ground to operate on.

The evolution on networks from the second generation of technology to the third generation technology could not be done without the help of operators. There are about 23 networks worldwide that operate on 3G technology. Some of these networks are only for test use but some are already in consumer based use.

Basically network operators need to find answers to three questions before they can start operating in the new field. What are the things to take into consideration during the change? How to manage the change? What will the future role be for the network operators?

Network operators have invested huge amounts on money into existing 2G networks. These networks have been around only for 10-15 years, and the investments made have not all paid of. Network operators need to find out ways of reusing their investments to build the 3G network. Because of the financial situation of the world today, network operators do not have new resources to invest into the future. They must recycle the old ones first.

Another thing network operators need to understand is that in the future their roles as we see today will change dramatically. In the future they will not only be network providers, they will be service providers. Network operators need to differentiate themselves in the markets, and one way is to concentrate on the content of the service and products. It is widely believed that in the future the markets will consist of content oriented service providers, since 3G technology allows any one willing to build software and sell it directly to end consumers. Thus network operators need to adapt to this change too.

There are several different paths from 2G to 3G. In Europe the main path will start from GSM where GPRS will be added to system. From this point it is possible to go to the UMTS system. In North America the system evolution will start from TDMA going to EDGE and from there to UMTS. [2]

Network Evolution

Considered at the highest level, evolution towards 3G is characterised by operator deployment of:

- A common core network with links to other mobile networks, the Fixed Telephone Network, ISDN, the Internet/Intranets and external data networks.
- Dual Radio Access Networks, operating with ability to work in several frequency bands and using complementary radio technologies (GSM/GPRS/EDGE).
- Dual-mode terminals carrying a USIM (UMTS Subscriber Identity Module), allowing subscribers to enjoy services on 2/2.5G and 3G networks.

On the Radio Access Network (RAN) side in particular, the mobile industry has developed the essential specifications and continues to work in partnership, coordinated via 3GPP at the global level, to further evolve the technology in order to support future market needs. The step-by-step approach reduces the risks that 3G is perceived to devalue old investments, and also provides significant improvements in the capability to deliver improved services at each step along the way. In all cases, each new release of the 3GPP standards provides backward compatibility, assuring an uninterrupted service capability for new and existing users alike. [13]

Layered Network Architecture Advantages

The UMTS system is based on layered services, unlike GSM. On the top there is the services layer, which will give advantages like fast deployment of services and centralized location. In the middle there is the control layer, which will help upgrading procedures and allow the capacity of the network to be dynamically allocated. On the bottom is the connectivity layer where any transmission technology can be used and the voice will transfer over ATM/AAL2 or IP/RTP. [2]

Mobile technologies evolution

The first new technology when going from GSM to UMTS is General Packet Radio Services (GPRS). It is the trigger to 3G services. The main point is that the network connection is always on, so the subscriber is online all the time. From the operator's point of view, it is important that GPRS investments are re-used when going to UMTS. Also capitalizing on GPRS business experience is very important.

From GPRS operators could go directly to UMTS, but they could also invest in an EDGE system. One advantage of EDGE is that there is no new licence needed as in UMTS. The frequencies will also be re-used and no new antennas are needed. The main thing is that subscribers will have to buy new EDGE terminals (devices).

The key point when going to UMTS is the use of the existing mobile network. From GSM core network side (Figure 14), the following system parts will be reused:

- MSC (Mobile switching centre)
- AUC (Authentication centre)
- HLR (Home location register)
- VLR (Visitor location register)
- EIR (Equipment identity register)

From GPRS network, the following system parts will be reused:

- SGSN (Serving GPRS Support Node)
- GGSN (Gateway GPRS Support Node)

From radio network, the following system parts will be reused:

- BSC (base station controller)
- BTS (base transceiver station)

The UMTS network will introduce new system parts that will give the functionality as given in standards:

- Node-B (base station)
- RNC (Radio Network Controller)
- MGW (Media Gateway)

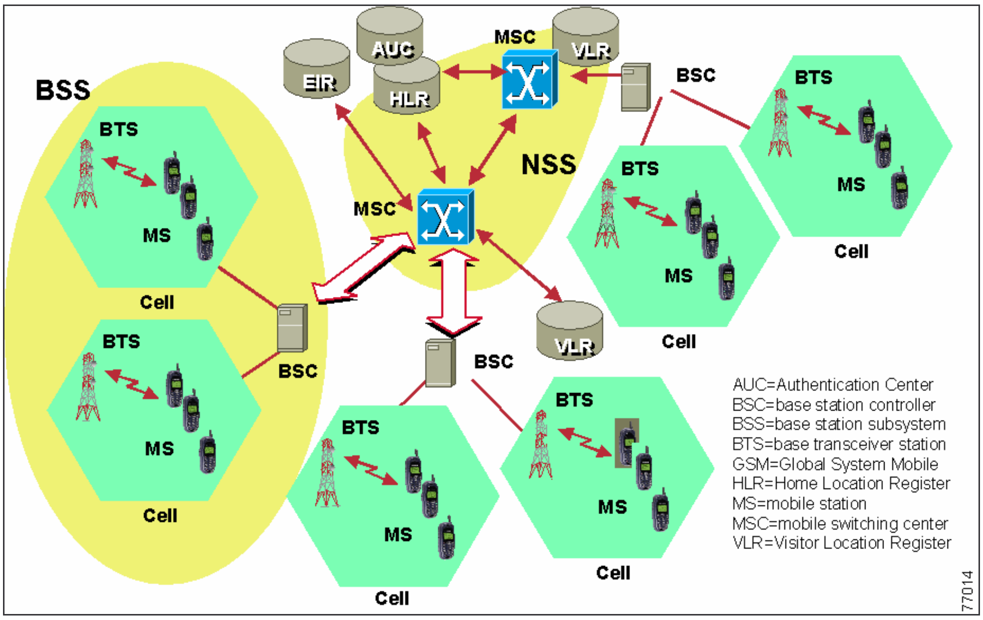

Figure 14: A detailed structure of a GSM network [5]

The functionality of MSC and SGSN will change when going to UMTS. In a GSM system MSC handles all the circuit switched operations like connecting A- and B-subscriber through the network. SGSN handles all the packet switched operations and transfers all the data in the network. In UMTS the MGW (Media gateway) will take care of all data transfer in both, circuit and packet switched networks. MSC and SGSN will act as "brains" of the system and they will control MGW operations. The name of the nodes will change into MSC-server and GSN-server. [2]

Terminal (Device) Developments

Mirroring developments on the radio access, core network and services evolution side, mobile terminal devices are themselves evolving to become more diverse, powerful, flexible and feature-rich. The mobile market is undergoing fundamental changes, just as the PC industry become “horizontalised” a decade ago. Different roles are appearing for platform providers, application providers, handset providers/integrators and other players. The changed business environment reflects market economics, as well as the fact that a mobile terminal no longer supports only telephony, but is evolving towards a device that can handle virtually all communication needs using a wide range of media types.

UMTS brings with it a wide range of new services and exciting handset models to the market, stimulating subscriber growth as well as traffic growth. For operators, much of the business appeal of UMTS lies in the ability to offer customers a wide choice of attractive new terminals.

This evolution can already be seen with the proliferation of colour screens and in-built digital cameras with e-mail, browser and PDA-type functions, as well as increasingly customizable user features on current handsets. Mobile handsets with in-built cameras may even outstrip combined sales of digital and film cameras within the near future, restructuring the image market by turning cameras into devices that users always carry with them.

Similar to the introduction of multi-band terminals that allowed users to roam between 900 MHz, 1800 MHz and 1900 MHz GSM networks, handsets are increasingly becoming multimode devices, capable of operating on GSM, GPRS and now WCDMA networks (Figure 15). It is likely that tomorrow's 3G customers will neither know – nor care – whether they are in an area of WCDMA, GPRS or GSM network coverage. They will simply use their personal terminal devices to access a portfolio of services and applications that are available to them at that instant via their user profiles. These profiles are governed by a USIM (UMTS Subscriber Identity Module) – the plug-in module resembling the SIM card found in GSM models today.

Figure 15: Multimode terminals combine support for GSM, GPRS and WCDMA networks [13]

Interoperability – the ability for services and applications to work seamlessly between networks and terminals – is likely to be a key issue in governing the uptake of 3G globally, and considerable industry resource is being invested in this area via initiatives such as OMA (Open Mobile Alliance). The first fruits of this concerted effort include MMS interoperability. While previous generations of mobile handsets have been essentially "hard wired" to perform a finite set of functions, network operators and manufacturers are now exploring the possibilities of downloadable software applications – such as games or information services – enabled by Java and other programming environments that are optimised for wireless delivery and use on handheld devices. [13]

Figure 16: Modern 3G device [13]

A wide choice of high-performance terminals is needed to experience and enjoy these new services. By mid-2005, over 180 different WCDMA terminal designs – spanning handheld terminals and PC data-card models – had already been launched or announced by American, Asian and European manufacturers (Figure 16). In addition, researcher Strategy Analytics has reported that 20 million WCDMA handsets were shipped during 2004, representing 3% of total global terminal sales. The performance and market appeal of earliest WCDMA terminals was restricted by factors including limited battery life, larger size and greater weight than their 2G peers. This situation has changed markedly, however. Latest designs now available to support mass-market consumer launches by 3G/UMTS operators compete head-to-head with the best available 2G phones in terms of performance, functionality, ease of use and aesthetic appeal. As well as support for 3G-specific services such as video-telephony, current models offer consumer-friendly features such as 256,000 colour screens and integrated MP3 stereo music playback capabilities. Reflecting the importance of digital imaging with consumers, multi-megapixel camera phones are now available from several manufacturers. The role of the terminal itself as a key driver for the mass market adoption of 3G/UMTS services has been well recognised by mobile operators, and indeed the majority of global players have coordinated their launch plans to coincide with the widespread availability of a choice of appealing, attractively priced terminals. This observation also explains the strategies of many operators who preceded consumer launches with commercial offerings to business customers based on a PC card. While allowing operators to fine-tune the performance of their WCDMA networks under 'real world' conditions, it has also provided the opportunity to gain experience of tariffing and usage patterns in advance of the widespread availability of consumer-friendly terminals. [13]

4.2 *From CDMAOne (2G) to CDMA2000 (3G)*

For CDMA operators, the transition from IS-95 (CDMAOne) to 1X and EV-DO (CDMA2000) is a relatively smooth process, with the technologies designed from the start to maximize the reuse of existing hardware. In so doing, operators can quickly roll out new technologies without disrupting their existing services and minimize their capital expenditures. There are several attributes which make this smooth transition possible.

An "In-Band" Evolution

1X is sometimes [incorrectly] referred to as a "2.5G" technology. At least part of the confusion has more to do with the outwardly subtle differences between 1X and IS-95 than with the underlying performance characteristics such as increased voice capacity and sector throughput. From its inception, the CDMA2000 evolution path was designed for "in-band" migration, meaning that operators could deploy the technology within their existing spectrum – spectrum that was likely being used to deliver 2G voice services. Therefore, if the working assumption was that new "3G spectrum" was required in order to deploy 3G, one might be able to understand how this misconception developed, even in advance of the first 1X network being deployed. As discussed earlier, the ITU did not explicitly require that 3G must be deployed in new spectrum. The ITU did, however, identify a wide range of spectrum bands, including those that were already being used for 2G technologies, which operators around the world could use to deploy and offer 3G services. These frequency bands include:

- 806-960 MHz
- 1710-2025 MHz
- 2110-2200 MHz
- 2500-2690 MHz

Further, the ITU recommendation also allows governments to deploy 3G in bands other than those identified above. There are a number of advantages to having an "in-band" evolutionary path:

Hardware Reuse

RF equipment, such as amplifiers, transmitters, receivers and filters, has to be customized for the frequency band in which it operates. By using the same spectrum that supports 2G services to deploy 3G, a large portion of an operator's 2G equipment can be reused. Major CDMA infrastructure suppliers offer multi-carrier RF solutions, which means that a given piece of hardware (e.g., an amplifier) can support several RF carriers, even if one carrier is 1X and another carrier is EV-DO. If 2G and 3G were deployed in different frequency bands, it would not be feasible to reuse the equipment, let alone use the equipment to simultaneously support 2G and 3G services. This attribute is discussed in more detail in an upcoming section. [6]

Ease of Network Engineering

Due to the laws of physics, wireless technologies that are deployed in higher frequency bands (UMTS bands) cannot transmit as far as wireless technologies deployed in lower frequency bands (2G bands). Although 3G technologies, including WCDMA, have more advanced features that can extend the coverage (e.g., improve the "link budget"), these enhancements are not enough to allow an operator to simply deploy its 3G sites where its existing 2G cell sites are located. Instead, an operator would have to deploy additional cells to fill in coverage gaps that would exist due to higher frequencies being used by its 3G than 2G networks. These coverage gaps would be most noticeable as 3G traffic increases due to the phenomenon called "cell breathing," in which the coverage offered by a CDMA2000 or WCDMA-based cell site actually shrinks as the network traffic increases. In addition to increasing an operator's capital expenditures, the requirement for more cell sites in the new frequency band also makes network engineering and optimization more challenging and time consuming, while ongoing operating expenses will also be higher due to the larger number of cell sites in the network. [6]

No Mandatory Auctions

European operators spent in aggregate more than $130 billion during the "3G Bubble" in order to acquire spectrum to deploy 3G services. Although some operators may have needed the spectrum to deploy 3G, other operators with unused spectrum were not given the flexibility of using their 2G spectrum for 3G services. By taking this approach, governments benefited from 3G in the form of a tax boon even before the networks were deployed. As a result, a number of operators were several billion dollars in the red before a single base station was ever deployed. Beginning in 2005 and continuing into 2006, "in-band" WCDMA infrastructure and devices will be coming available. As the market for these solutions develops over the next few years, and as governments relax their requirements and allow 3G to be deployed in "2G spectrum," these operators will eventually be able to recognize similar advantages that CDMA operators have been experiencing since the inception of 3G. These operators, however, will still require entirely new RAN (Radio Access Network [13]) infrastructure since legacy GSM base stations cannot be retrofitted for WCDMA. [6]

Maintaining the 1.25MHz Carrier

Beginning with IS-95 (2G) and continuing through at least Revision B (3G), 1X and EV-DO utilize a 1.25MHz radio channel to send voice and data traffic from the base station to a mobile device and a separate 1.25MHz radio channel to send voice and data traffic from the mobile device to the base station. The path from the base station to the mobile device is referred to as the forward link or down link, while the path from the mobile device to the base station is referred to as the reverse link or uplink. The term used to describe traffic that requires separate frequencies for the forward link and reverse link is FDD (Frequency Division Duplexing), while in a TDD-based system (Time Division Duplexing), the same radio carrier supports the forward link and the reverse link traffic, with a short time interval used to separate the transmissions in each direction.

While the advantages of retaining a 1.25MHz carrier may not seem obvious and noteworthy, from an operator's perspective, the advantages are actually quite profound. Spectrum is a limited resource and it becomes even scarcer as network usage increases, which in turn means that an operator is committing most, if not all, of its spectrum to supporting existing services.

When an operator deploys a new technology (e.g., 3G) it must free up some of its spectrum and dedicate it to the new technology, unless it happens to have some unused spectrum available. The challenge, of course, is that by freeing up spectrum that is already being used, it places an even greater burden on its remaining 2G spectrum, which ultimately can lead to higher dropped call rates, network busy signals, and customer dissatisfaction. This occurrence is particularly prevalent when backward compatibility does not exist between the two technologies.

When the new technology requires a different [wider] amount of spectrum, the problem becomes even more challenging since it requires an operator to free up more spectrum and displace several RF carriers. For GSM operators migrating to WCDMA, it is somewhat of a Catch 22 situation (vicious circle [12]) since, although WCDMA supports more voice capacity than GSM, operators may not have enough spectrum to free up without severely degrading its 2G network; WCDMA utilizes a 5MHz FDD channel and GSM utilizes a 200kHz FDD channel, which equates to approximately 25 GSM radio carriers in a single WCDMA radio carrier. Further, even if the spectrum is available, the operator may have to reassign frequencies across its network of base stations in order to assemble 5MHz of contiguous spectrum.

In this case the problem is magnified since WCDMA is not backward compatible with GSM without the use of multi-mode WCDMA/GSM mobile devices. This means that unless the operator is able to rapidly increase its 3G subscriber base, for example through the use of large handset subsidies, the additional voice capacity that is possible on its 3G [WCDMA] network would not be realized since its subscribers would still be using the 2G [GSM] network. Recall that with 1X, the handsets are forward and backward compatible with IS-95, which is not the case with WCDMA and GSM.

As previously noted, IS-95, 1X and EV-DO all use 1.25MHz of FDD spectrum. Further, given the special characteristics of CDMA-based systems, including WCDMA, each active frequency can potentially be assigned to every single cell site in an operator's network. This frequency reuse scheme (N=1) is not easily achieved with TDMA-based systems, such as GSM. Thus, a CDMA operator only has to free up one RF carrier to deploy a new technology (e.g., EV-DO). Conversely, GSM operators who are deploying an "in-band" WCDMA system would have to not only find and allocate 5MHz of contiguous spectrum, it would also have to design an entirely new frequency reuse scheme with its remaining RF carriers in order to ensure that inter-cell interference in its GSM network does not develop. As discussed in the next section, backward compatibility makes the 3G transition even simpler. [6]

Backward and Forward Compatibility

Perhaps the most compelling feature of the CDMA2000 evolution is that, in addition to increasing voice capacity and supporting mobile data applications, it is largely backward and forward compatible. So what is backward and forward compatibility and why is it advantageous for an operator?

Forward compatibility means that a new technology can be deployed in an operator's network and mobile devices that are based on an "old technology" would still operate with the new technology as if nothing had ever happened. Conversely, mobile devices that are based on a new technology would still work on networks that are based on an old technology – this is referred to as backward compatibility. This bi-directional compatibility feature is highly attractive for an operator that is spectrum constrained, or for an operator that wants to take a phased approach to evolving from 2G to 3G services.

Case in point, Sprint Nextel (Sprint PCS at the time) began selling 1X phones in late 2002, but it didn't launch nationwide CDMA2000 services until the early fall of 2003. By taking this approach, Sprint Nextel was able to seed the market with 3G phones, thus when it launched 3G services it was immediately able to reap the voice capacity benefits that CDMA2000 offers. Equally important, when Sprint Nextel launched 1X, existing IS-95 phones that were already on its network were fully operational on a 3G radio carrier, even though those phones were based on a 2G technology. As a result, the 1X radio carrier did not go unused if there were not any 3G phones present.

It should be noted that EV-DO Release 0 is not backward compatible with 1X or IS-95. This approach was taken in order to take advantage of an all-IP network and to maximize the performance of an all data network without having to support circuit switch voice services (e.g., 1xEV-DV). However, EV-DO does maintain backward compatibility through the use of multi-mode devices that support EV-DO, 1X and IS-95. As a result, an EV-DO mobile device can seamlessly roam between EV-DO, where it can take advantage of the technology's enhanced data capabilities, and 1X, where the EV-DO services and applications are still available, albeit with 1X performance characteristics.

In that regard, WCDMA is largely comparable from a device point of view since multimode WEDGE (WCDMA + EDGE/GPRS/GSM) devices support continuity of services between 3G and 2G network boundaries. The primary difference, however, is from a network infrastructure perspective since WCDMA and EDGE/GPRS/GSM potentially require different spectrum blocks and may require standalone RAN equipment, thus increasing the cost and complexity of the networks(s).

Once an operator has deployed EV-DO Release 0, the evolution to EV-DO Revision A and Revision B is fully backward and forward compatible, with a large amount of hardware reuse within the network infrastructure. With backward and forward compatibility intact, CDMA operators have flexibility to choose how, when, and where they evolve their network without concerns about disrupting services for existing subscribers. With this flexibility, an operator could upgrade its entire EV-DO Release 0 network to Revision A (Revision B), thus allowing it to take advantage of the enhanced features associated with the later revisions while at the same time still supporting existing Release 0 mobile devices. Alternatively, the operator could migrate portions of its EV-DO network to Revision A (Revision B) based on its own particular requirements and provide seamless roaming for EV-DO devices between Revision A (Revision B), EV-DO Release 0, and even to 1X/IS-95 with the use of multi-mode devices. [6]

The Impact on the Network Infrastructure

In the previous section, the advantages of backward and forward compatibility from a network services and mobile device point of view were highlighted. In this section, we'll examine the impact of the evolution on an operator's existing CDMA network infrastructure.

The Core Network Evolution

It is important to realize that the RAN and CN (core network) do not have to evolve together, with separate standards used to define the RAN and the CN requirements and technical specifications. Like the 1X and EV-DO RAN migration, the CN migration is relatively straightforward with a clear migration path to an all-IP core transport and switching architecture that supports MMD (Multimedia Domain) applications and services.

The WCDMA core network and its migration path are very comparable with new network elements required to support packet services (e.g., GPRS and then WCDMA). In fact, the 3GPP2 (Third Generation Partnership Project 2) has recognized the work that the 3GPP (Third Generation Partnership Project) has done with IMS (IP Multimedia Subsystem) and has adopted it in large part, albeit with modest modifications to support specific needs. [6]

IS-95 to 1X and EV-DO

In the core network, new hardware elements, including the PDSN (Packet Data Server Node), FA (Foreign Agent), AAA (Authentication, Authorization and Accounting server) and a HA (Home Agent) (HA), are required when migrating from IS-95 to 1X to support 1X data services. However, in their absence an operator could still utilize 1X for voice capacity gains and then deploy the packet core network when it is ready to begin offering data services. When an operator deploys EV-DO, the same core network elements are reused, although the operator will likely increase its backhaul capacity to coincide with the capabilities of the higher throughput air link. [6]

The Transition to IP Multimedia Domain

Until recently, mobile communications systems (e.g., 1G, 2G and 3G) lacked the capabilities to support a full end-to-end IP core network. As a result, real-time services such as voice were handled by a circuit switch network, while less time sensitive applications were handled by a packet data core network (e.g., IP routing and transport). As an example, the video telephony feature of WCDMA is actually a 64kbps circuit switch connection, even though the video telephony application is considered to be a "data application."

With the introduction of EV-DO Revision A and its inherent ability to support QoS (Quality of Service) and low latency applications on an IP RAN, it is now possible to extend IP throughout the radio access and core network and offer non-real-time and time sensitive applications on the same packet network.

From an operator's point of view, this is a very attractive proposition since over time it can migrate its voice and data traffic to a more scalable [all-IP] network and effectively "turn off," or at least scale down, its circuit switch network. In addition to reducing capital expenditures and operating expenses, it is possible to seamlessly integrate voice and data services to provide subscribers with a more compelling multimedia experience. Over the last eighteen months, there has been a lot of focus, and rightly so, on IMS, which is a feature of Release 5 within the 3GPP [WCDMA] standard. With many of the 3GPP2 members also supporting the development of the 3GPP standards and the work within the IETF (Internet Engineering Task Force), the decision was made to leverage this work and adopt it within 3GPP2, albeit with subtle differences. Thus the 1X and EVDO evolution is largely comparable to the 3GPP evolution within the core network.

In addition to a network architecture that is SIP (Session Initiation Protocol) based, and in which the signaling and bearer traffic are separated for a more effective use of network resources, MMD supports convergence across multiple access technologies, including WLAN (wireless local area network), WWAN (wireless wide area network), and fixed line.

Operators can also leverage MMD to offer new services, including:

- Push-to-talk/see
- Video telephony
- Multimedia conferencing
- Person-to-person gaming
- Interactive shows and events

MMD is not a requirement, and operators could upgrade the RAN to EV-DO Revision A in order to take advantage of its improvements without fully realizing its capabilities throughout the network. However, it is likely that operators will eventually move toward an all-IP core network that supports MMD. [6]

5 Interworking of 3G and 4G

Researchers and vendors are expressing a growing interest in 4G wireless networks that support global roaming across multiple wireless and mobile networks—for example, from a cellular network to a satellite-based network to a high-bandwidth wireless LAN. With this feature, users will have access to different services, increased coverage, the convenience of a single device, one bill with reduced total access cost, and more reliable wireless access even with the failure or loss of one or more networks. 4G networks will also feature IP interoperability for seamless mobile Internet access and bit rates of 50 Mbps or more. Because deployment of 4G wireless technology is not expected until 2006 or even later, developers will hopefully have time to resolve issues involving multiple heterogeneous networks such as:

- access,
- handoff,
- location coordination,
- resource coordination to add new users,
- support for multicasting,
- support for quality of service,
- wireless security and authentication,
- network failure and backup, and
- pricing and billing.

Network architectures will play a key role in implementing the features required to address these issues. [15]

5.1 *Possible Architectures*

One of the most challenging problems facing deployment of 4G technology is how to access several different mobile and wireless networks. Figure 17 shows three possible architectures: using a multimode device, an overlay network, or a common access protocol.

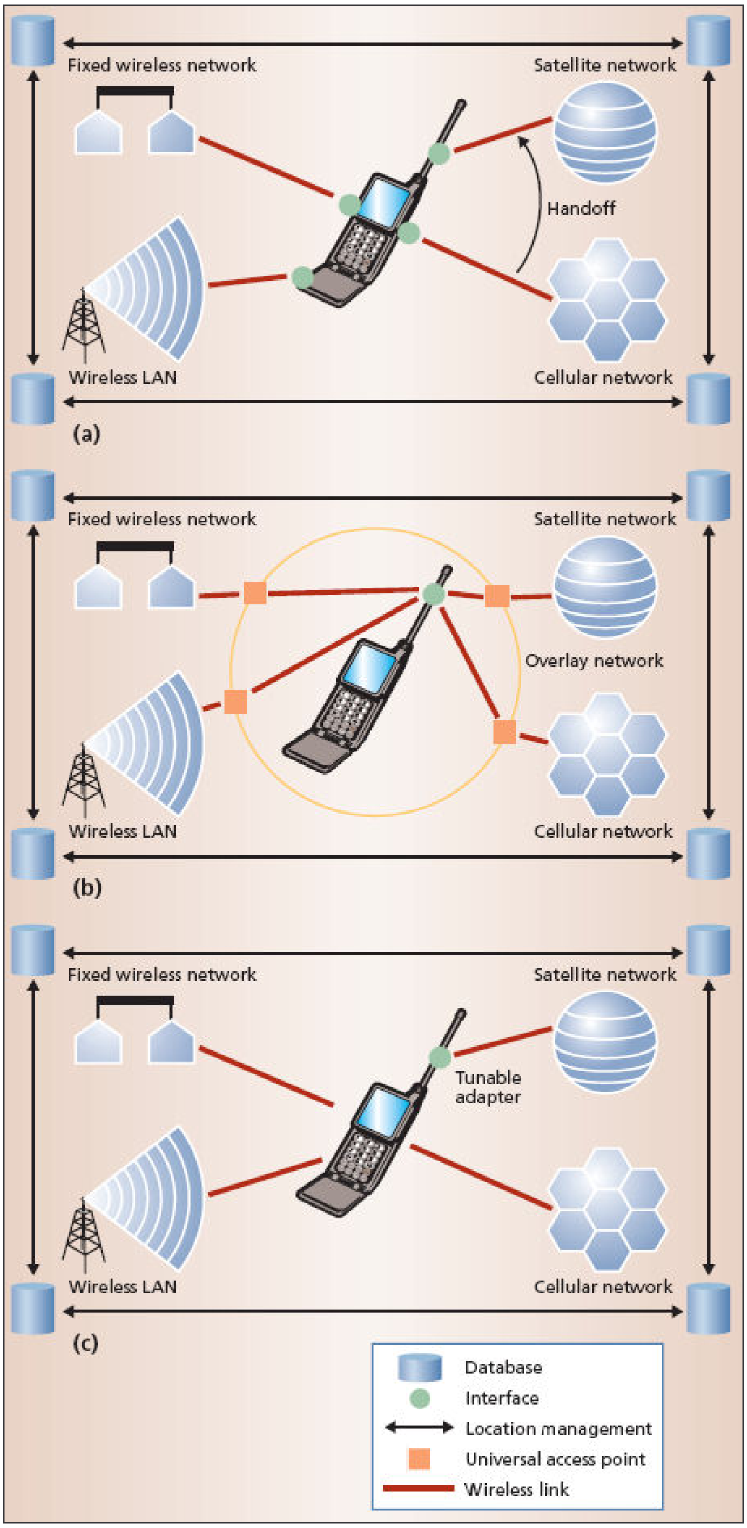

Figure 17:

(a) A multimode device lets the user, device, or network initiate handoff between networks without the need for network modification or interworking devices.

(b) An overlay network—consisting of several universal access points (UAPs) that store user, network, and device information—performs a handoff as the user moves from one UAP to another.

(c) A device capable of automatically switching between networks is possible if wireless networks can support a common protocol to access a satellite-based network and another protocol for terrestrial networks. [15]

Multimode devices

One configuration uses a single physical terminal with multiple interfaces to access services on different wireless networks. Early examples of this architecture include the existing Advanced Mobile Phone System/Code Division Multiple Access dual-function cell phone, Iridium's dual-function satellite-cell phone, and the emerging Global System for Mobile telecommunications/Digital Enhanced Cordless Terminal dual-mode cordless phone. The multimode device architecture may improve call completion and expand effective coverage area. It should also provide reliable wireless coverage in case of network, link, or switch failure. The user, device, or network can initiate handoff between networks. The device itself incorporates most of the additional complexity without requiring wireless network modification or employing interworking devices. Each network can deploy a database that keeps track of user location, device capabilities, network conditions, and user preferences. The handling of quality-of-service (QoS) issues remains an open research question. [15]

Overlay network

In this architecture, a user accesses an overlay network consisting of several universal access points. These UAPs in turn select a wireless network based on availability, QoS specifications, and user-defined choices. A UAP performs protocol and frequency translation, content adaptation, and QoS negotiation-renegotiation on behalf of users. The overlay network, rather than the user or device, performs handoffs as the user moves from one UAP to another. A UAP stores user, network, and device information, capabilities, and preferences. Because UAPs can keep track of the various resources a caller uses, this architecture supports single billing and subscription. [15]

Common access protocol

This protocol becomes viable if wireless networks can support one or two standard access protocols. One possible solution, which will require interworking between different networks, uses wireless asynchronous transfer mode. To implement wireless ATM, every wireless network must allow transmission of ATM cells with additional headers or wireless ATM cells requiring changes in the wireless networks. One or more types of satellite-based networks might use one protocol while one or more terrestrial wireless networks use another protocol. [15]

5.2 *Quality of Service*

Supporting QoS in 4G networks will be a major challenge due to varying bit rates, channel characteristics, bandwidth allocation, fault-tolerance levels, and handoff support among heterogeneous wireless networks. QoS support can occur at the packet, transaction, circuit, user, and network levels.

- **Packet-level QoS** applies to jitter, throughput, and error rate. Network resources such as buffer space and access protocol are likely influences.
- **Transaction-level QoS** describes both the time it takes to complete a transaction and the packet loss rate. Certain transactions may be time-sensitive, while others cannot tolerate any packet loss.
- **Circuit-level QoS** includes call blocking for new as well as existing calls. It depends primarily on a network's ability to establish and maintain the end-to-end circuit. Call routing and location management are two important circuit-level attributes.
- **User-level QoS** depends on user mobility and application type. The new location may not support the minimum QoS needed, even with adaptive applications.

In a complete wireless solution, the end-to-end communication between two users will likely involve multiple wireless networks. Because QoS will vary across different networks, the QoS for such users will likely be the minimum level these networks support. [15]

End-to-End QoS

Developers need to do much more work to address end-to-end QoS. They may need to modify many existing QoS schemes, including admission control, dynamic resource reservation, and QoS renegotiation to support 4G users' diverse QoS requirements. The overhead of implementing these QoS schemes at different levels requires careful evaluation. A wireless network could make its current QoS information available to all other wireless networks in either a distributed or centralized fashion so they can effectively use the available network resources. Additionally, deploying a global QoS scheme may support the diverse requirements of users with different mobility patterns. The effect of implementing a single QoS scheme across the networks instead of relying on each network's QoS scheme requires study. [15]

Handoff delay

Handoff delay poses another important QoS-related issue in 4G wireless networks. Although likely to be smaller in intranet-work handoffs, the delay can be problematic in internet-work handoffs because of authentication procedures that require message exchange, multiple-database accesses, and negotiation-renegotiation due to a significant difference between needed and available QoS. During the handoff process, the user may experience a significant drop in QoS that will affect the performance of both upper-layer protocols and applications. Deploying a priority-based algorithm and using location-aware adaptive applications can reduce both handoff delay and QoS variability. When there is a potential for considerable variation between senders' and receivers' device capabilities, deploying a receiver-specific filter in part of the network close to the source can effectively reduce the amount of traffic and processing, perhaps satisfying other users' QoS needs. [15]

Although 4G wireless technology offers higher bit rates and the ability to roam across multiple heterogeneous wireless networks, several issues require further research and development. It is not clear if existing 1G and 2G providers would upgrade to 3G or wait for it to evolve into 4G, completely bypassing 3G. The answer probably lies in the perceived demand for 3G and the ongoing improvement in 2G networks to meet user demands until 4G arrives. [15]

6 Conclusion

After studying all the available technologies that formed in the past, and will be the future of the Cellular Wireless Networks, we can see that the big question of the interworking issue is which technology the operators will choose in order to evolve their networks and services. Which way will they choose between the rivaling technologies WCDMA or CDMA2000? The best way to answer to this question and to complete this document is to cite the extract of a report named "Operator Options for 3G Evolution" written by Bengt Nordström. Bengt Nordström is the CEO Northstream, which is a leading wireless advisor.

A technology evolution path decision should be driven by the future profitability impact that the decision will have: with which technology can the operator maximize his future revenue? Which path requires least additional investment, considering the legacy situation?

A technology evolution path decision is a long-term decision. Because a technology generation shift is generally very expensive it cannot be done often, and therefore it is irrelevant what is gained in the short term if the 5-10 year profitability impact is negative. Bad services do not mean bad networks technology. The introduction of data services decouples the service offering from the network technology. This means that an operator can easily fail to offer compelling services despite having an excellent underlying network technology. Higher data rates as such are not a main driver for data services uptake. The services envisaged for mass-market adoption of mobile data are typically not data rate demanding.

We conclude that GSM operators generally will choose the WCDMA evolution path, says Bengt Nordström. According to the report, investment reusability, gradual investments, simpler service migration, more attractive services (primarily roaming) and a better long-term terminal market, combine to make this decision rather simple. GSM operators who face difficulties to find spectrum for a WCDMA deployment, for example in North America, should rather use EDGE as bridging technology until spectrum for WCDMA becomes available, than choosing a CDMA2000 evolution.

For CDMAOne operators the generally preferable path is to evolve its network to CDMA2000 1X (which has similar service-enabling capabilities to GPRS) and then on to DO and/or DV. Spectrum availability, investment reusability, gradual investments, simpler service migration and lack of CDMA/WCDMA terminals, combine to make this a straightforward decision.

For a TDMA operator we view both WCDMA- and CDMA-based evolution paths as feasible. High economies-of-scale, more attractive services (primarily roaming) and a more attractive long term terminals market all speak for WCDMA. Against these factors stand the prospects of simpler spectrum management, gradual investments enabled by AMPS/CDMA terminals and higher investment reusability, which speak in favour of CDMA2000. Whichever option is adopted the TDMA operators will have to make sure they have the solid backing of its suppliers to provide them with confidence in making this difficult decision.

An overall conclusion is that GSM/GPRS will continue to dominate the global market for years to come, says Bengt Nordström. WCDMA will be the dominant 3G technology in the long term, considering the dominance of existing 3G networks and already made decisions on GSM-to-WCDMA evolution.

Figure 18 shows a chart that represents the mobile infrastructure forecast of each one of the technological standard we have previously examined.

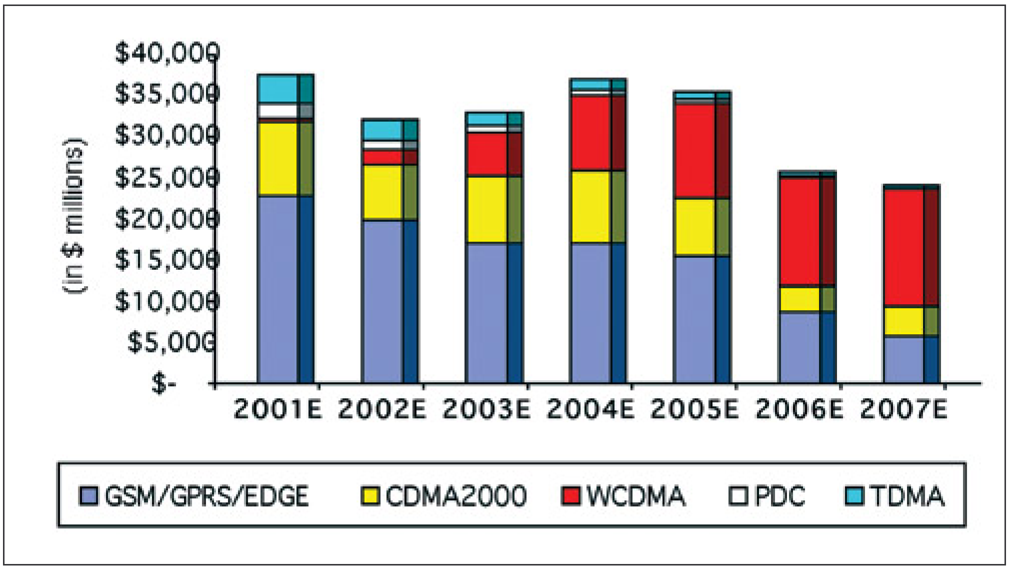

Figure 18: Mobile Infrastructure Forecast by Technology [8]

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Creativyst (pronounced "kree.ATE.tiv.vist") is dedicated to providing the best and most reliable software products and services to help automate your business, improve your web site, and develop your applications.

[2] URL: http://dictionary.laborlawtalk.com/

This site provides information on terms of various types such as encyclopedic, legal, medical, computer and science.

[3] Continuous Computing, "Wireless Network Evolution",
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Continuous Computing provides Network Service-Ready Platforms™ that enable telecom equipment manufacturers to rapidly deploy converged communications. Over 150 customers worldwide use Continuous Computing as the foundation for their wireless, VoIP and IMS applications.

[4] Xilinx, URL: http://www.xilinx.com

Xilinx leads one of the fastest growing segments of the semiconductor industry - Programmable Logic Devices (PLDs) - with over 50 percent market share in calendar year 2004 according to Gartner Dataquest. PLDs represent an exciting growth potential in the chip market thanks to their flexible nature and ability to change functionality even after being manufactured. Gartner Dataquest forecasts the PLD market to grow to $4.5 billion in 2006, $5.2 billion in 2007 and $6.3 billion in 2008.

[5] Cisco Systems, Inc, URL: http://www.cisco.com

Cisco Systems, Inc. is the worldwide leader in networking for the Internet. Today, networks are an essential part of business, education, government and home communications, and Cisco Internet Protocol-based (IP) networking solutions are the foundation of these networks. Cisco hardware, software, and service offerings are used to create Internet solutions that allow individuals, companies, and countries to increase productivity, improve customer satisfaction and strengthen competitive advantage.

[6] The CDMA Development Group (CDG), URL: http://www.cdg.org

The CDMA Development Group (CDG), founded in December 1993, is an international consortium of companies who have joined together to lead the adoption and evolution of 3G CDMA wireless systems around the world. The CDG is comprised of CDMA service providers and manufacturers, application developers and content providers. By working together, the members help to ensure interoperability among systems, while expediting the availability of 3G CDMA technology to consumers.

[7] Europa Technologies Limited, "GSM World Coverage 2005" - Edition C, September 2005,
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Europa Technologies is a leading digital map data manufacturer specialising in global mapping and point data for Location Based Services (LBS). The company's products are used by over 120 of the worlds Fortune 500 companies plus several missions of the United Nations. Europa Technologies also offers professional services including software and map data development, international geocoding and consultancy.

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MPD/Microwave Product Digest is the premier new product magazine devoted to information on components, equipment and subsystems for the RF, microwave and wireless industries. Each issue of MPD provides news, data and application information that engineers and engineering managers working in commercial or military markets can use to develop their systems, subsystems, and designs.

[9] COSMOTE, "GSM coverage map of Greece", URL: http://www.cosmote.gr/content/el/sections/company/company/kalypsi.html

COSMOTE is the leading provider of mobile telecommunications services in Greece with an estimated market share of approximately 38%.

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This site hosts a free on-line encyclopedia.

[13] The UMTS forum, URL: http://www.umts-forum.org

The UMTS Forum is an open, international body for promoting the global uptake of UMTS third generation (3G) mobile systems and services.

[14] eXpansys®, URL: http://www.expansys.com/

eXpansys® is a subsidiary of Mobile and Wireless Group (MWG.COM) the largest specialist retailer of wireless technology in Europe and North America.

[15] The IEEE Computer Society, URL: http://www.computer.org

With nearly 100,000 members, the IEEE Computer Society is the world's leading organization of computer professionals. Founded in 1946, it is the largest of the 39 societies of the IEEE. The IEEE Computer Society's vision is to be the leading provider of technical information, community services, and personalized services to the world's computing professionals.