Alexandre Paquet

UMTS: the evolution of GSM toward IMT-2000

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Dr. Takis Mathiopoulos

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University of British Columbia
Department of Electrical Engineering
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Table of Contents:

List of Figures:

List of Tables:

Abstract

Mobile telecommunications and internet-related applications are probably the two fastest growing markets currently witnessed. The incredible penetration of personal communications systems (particularly GSM) as well as the increasing number of Internet connections have asked the industry to come up with solutions to combine the multimedia capacities of the World Wide Web with the flexibility of wireless communications. Although development and standardisation work is still on the way, it's highly likely that third-generation systems will satisfy the 21st century networks' needs for a wide range of services from voice to low, high, and advanced data rate services to support mobile multimedia such as video streaming or video conferencing. In the International Telecommunications Union, third-generation system is called International Mobile Telecommunications of the year 2000, while in Europe, it is called Universal Mobile Telecommunications System and both aim at providing communications of any kind, anytime, anywhere. Wideband Code Division Multiple Access is the air interface that has come up as the best solution for third-generation schemes while providing backward compatibility with existing second-generation CDMA-based networks. This article focuses on standardization procedure, both at ITU and ETSI levels, in addition to their market and technical requirements. The practical approach of 3GPP mainly derived from the present GSM systems, as well as the reasons and technical challenges involved in the choice of WCDMA are then highlighted.

Introduction

Since the early 1980s, when the first generation mobile systems were introduced, mobile communications has experienced enormous growth. The first systems such as AMPS, TACS and NMT, using analog transmission, were pretty basic allowing the transmission of speech and only speech. Then, in the late 1980s, the use of digital communications has allowed second-generation systems to add low-bit-rate data to speech transmission. Second-generation systems, like GSM, PDC, IS-136 and IS-95, have evolved in generation 2.5 by allowing more advance services such as medium-bit-rate data transmission. However, the sharp increase in data transmission and customers' ever growing needs have challenged the industry to come up with new ways to face the challenge of the 21st century information society. A lot of technical components already help the enhancement of contemporary systems and will continue to do so in the future. In addition to those practical improvements, a large part of the work still has to be done in the form of standardization procedures in order to reach the third-generation systems' goal. Those need to be well planned and clearly defined to provide several new innovative services and in particular the broadband multimedia capabilities. Work is currently under way in different standardization bodies and hope is that the future of public land wireless communications systems will be made commercially available during the current year.

In this paper, we will discuss key issues involved in the IMT-2000 (International Mobile Telecommunications in the year 2000) third-generation wireless communications standard. First, we will explain why such standardization procedure is necessary and we will present few steps of that process and give a portray of its history. Then, we will explain the main principles behind the third-generation standards and describe the key features of IMT-2000 necessary to fulfil them. Finally, we will see the major evolutions from the second-generation schemes that will make available true multimedia wireless systems. In a second part, we will turn our attention toward one of the members of the ITU family of standards: UMTS (Universal Mobile Technology System) and see how it has *naturally* evolved from the existing European Global System for Mobile Communications (GSM). We will also present how the standardization procedure takes place within the European Telecommunications Standard Institute (ETSI) as well as some specific characteristics of UMTS. A brief description of the radio system design for that standard will then be given before we explain the motivations of the choice of the wideband code-division multiple access (WCDMA) for frequency duplex division bands. Finally, we will point out the principal features of UMTS allowed by the utilization of WCDMA and try to make clear why this particular method has attracted so much attention for IMT-2000's air interface.

IMT-2000

1. Justification of IMT-2000 standardization process

The definition of a standard is *usually a set of rules or technical specifications adhered to by a producer either tacitly or as a result of a formal agreement* [1]. Fundamentally, regulatory matters are national issues. However, in some cases, regional and global harmonization of regularization and policy issues is desirable. The idea is to achieve the standardization by persuading all interested parties to work toward unity of technologies that otherwise might compete against each other. In the modern world, money issues often motivate such a process. It is the case here since standardization is greatly effective in today's wireless world because it facilitates interconnections between networks, inter-operability over network/terminal interface and helps free movement and trade of equipment [2].

The ITU, which is the United Nations organization responsible for harmonizing global telecommunications, needs to develop a new standard able to deal with the increasing amount of data (among which video) transmitted. ITU, for International Telecommunications Union, and particularly ITU-T (telecommunication standardization group) is responsible for the process and assure the liaison between different standardization organizations [4]. The process also intends to keep up with the increasing popularity of wireless communications that asks for rapid enhancement of capacity of networks to deliver good QoS as well as a rapid improvement in the quality and level of access to global telecommunications [3]. The International Mobile Telecommunications in the year 2000 (IMT-2000) standard aims to advance and unify the diverse systems we have today into a common flexible radio infrastructure in order to be able to provide communications at any time, at any place, in any form. ITU's work is really needed since it is crucial if one wants to allow movement from a collection of unique mobile systems (each with its own standard) toward the future world of global personal mobile telecommunications [3]. Finally, the last, but certainly not the least reason that asks for international standardization is the fact that in order to provide global roaming to moving users, telecommunications providers must be able to assure the interconnectivity between networks which can be guaranteed only if strict international regulations exist.

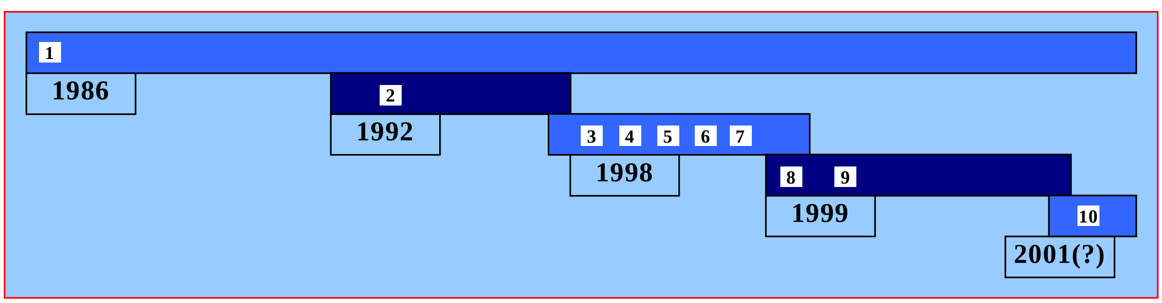
2. Review history of IMT-2000

The ITU has started being involve in standardization of wireless communications around 1986 when the availability of wireless phone made imaginable the concept of global, rather than national/regional land mobile systems [3]. Later on, in 1992, the physical basis of the Future Public Land Mobile Telecommunications Systems (FPLMTS) were set during the ITU World Administrative Radio Conference (WARC-92) when 230 MHz in the 2GHz band (1885 to 2025 *MHz* and 2110 to 2200 *MHz*) were identified for its satellite and terrestrial components.
Subsequently, a formal request by the ITU-R was distributed for submission of candidate radio transmission technology (RTT) for IMT-2000 with a closing date of June 1998 [1].

By that time, in January 1998, the European Telecommunications Standards Institute (ETSI), which had formed with its partners the third-generation partnership project (3GPP) to deal with the progression of standardization, selected basic technology for the Universal Mobile Telecommunications System (UMTS, the European version of IMT-2000) terrestrial radio access (UTRA) system among which the use of both WCDMA and TD-CDMA were selected. In March 1998, the Telecommunications Industry Association (TIA) TR45.5 committee, responsible for IS-95 standardization in the United States, adopted a framework for WCDMA (now known as cdmaOne or also CDMA-2000) that would be backward compatible to IS-95 systems. During that same year, in late April this time, Qualcomm reported to ETSI that unless the UMTS proposal provided backward compatibility to IS-95 (the North-American standard), it would not grant access to the intellectual property the American company claimed was essential to WCDMA development [1]. This was a serious problem in the standardization procedure since it turned into a contentious trade issue between the U.S. and the European Union regarding violations of intellectual properties on RTTs. It was absolutely necessary to solve that dispute since the standard aimed to be a worldwide one and not another *regional* one. Nevertheless, by the end of June 1998, there were 10 proposals submitted to the ITU-R for candidate RTTs on the IMT-2000 terrestrial component from the USA, Europe, Japan, China and Korea [1]. Almost all of them were proposing the use of CDMA as the choice for multiple access technique.

An agreement on the support of a unique world CDMA standard was finally announced between Qualcomm and Ericsson at the end of March 1999. This disagreement certainly slowed down the progress of the IMT-2000 standardization procedure but it definitely showed the importance of clarifying the Intellectual Property Rights (IPR) issue in the IMT scheme. Furthermore, the value of ITU as a standard forum in the sense of providing common ground to reach consensus was also made obvious a that time.

More recently, in November 1999, a broad set of radio interface specifications incorporating the flexibility required was approved by the ITU-R Task Group 8/1 and after few postponing, the IMT-2000 is in fact thought to be operational sometime during the year 2001 [4]. In fact, a partial launch is planned for May 2001 in Japan.



1. Involvement of ITU in standardization
2. WARC-92, physical basis of FPLMTS
3. 3GPP formed to work on UMTS
4. ETSI selects basic technologies for UTRA
5. CDMA chosen by TIA
6. WCDMA problem between Qualcomm & ETSI
7. Limit for RTT submissions (10 proposals)
8. Qualcomm & Erickson agree on CDMA standard
9. Radio interfaces specifications adopted by ITU-R
10. IMT-2000 in functions

Figure 1 Timeline of the IMT-2000 standardization

3. Key Principles of IMT-2000

As we have previously said, the evolution of information technologies has set up new key principles by which wireless systems should operate. Customers will be (and some of them probably are already) asking for improvement in networks' capabilities to suit their ever-growing need for information transmission. We present here an overview of the key principles behind ITU's work in order to get a better understanding of what are the technical challenges involved here.

Third Generation Mobile Systems will implement one's dream of anywhere, anytime communications with a lightweight and convenient pocket communicator and this is certainly the main purpose of IMT-2000 [4]. It will also expand the range of services since wireless facilities of the future must be able to provide, in addition to high quality voice communications, a variety of data services in order to offer a wide range of applications (ranging from Internet access to file transfer and video conferencing) [3]. Of course, in order to achieve such a service variety, broadband transport technologies have to be used (in opposition to narrowband ones used in today's second generation mobile systems). In order to be able to fulfil the multimedia services, a bit rate of 2 Mbps has been proposed for IMT-2000 for the first phase and another one of 20 Mbps has been envisaged for a future development.

Another important issue involve in the definition of IMT-2000 is that ITU (and the wireless communications industries as well as the customers) wants to get a unified, seamless infrastructure. As a matter of fact, one of the main purposes of the standardization process is to regroup many of the today's existing systems (paging, cellular, cordless, etc.) within one unified radio network to be able to offer a wide range of services [3]. This characteristic of IMT-2000 should allow the service providers to increase the operating efficiencies (one bigger service instead of many small ones) while offering a more user-friendly service. In the same line of thoughts, the integration of mobile and fixed networks will make possible the provision of fixed network services over the wireless channels but, in the meantime, it also increases the QoS expect from wireless networks. In fact, one of the goals of the developers of the IMT-2000 family is to provide a *wireline* quality of service with wireless freedom [9].

Another goal of IMT-2000 is to bridge the telecommunications gap. More than ever, the difference in technology's availability between developed and developing countries and particularly the price for it, slows down the expansion of wireless (and, in fact wired too) communication systems in the later ones. The general acceptance of IMT-2000 as an international standard should lead to low cost systems and handsets thus helping developing countries stepping into the 21st century wireless technologies in a more efficient way [3].

IMT-2000 success depends on the availability of self-adaptive, reprogrammable terminals. This is base on the fact that no matter how well designed a system is, it is never flawless. The objective here is to be able to access one's terminal from a distance (by sending software updates directly to the handset) to correct errors or simply to add new features. This is driven by the high complexity (and cost) of recalling and reprogramming an important number of telephones. Another way of using that would be within arrival at an airport, a user could reprogram his phone in order to match with all the characteristics of the local system. It has to be kept in mind that even tough IMT-2000 tends to unify all the local standards into one global international standard some small differences (that could prevent a phone from working at all) would still persist because of the cultural diversity leading to different needs [3]. By assuring the development of self-adaptive handset, the industry secures the global roaming capabilities.

The last but certainly not the least principle of the IMT-2000 standard's purpose is to deliver equal communication quality independently of the user location or call destination. The *virtual home environment* **(**VHE) means that the user shouldn't be able to notice any differences in QoS, including speech quality, transport capabilities, source (speech, video or data) coding, etc., either he is in North America or Europe, in his car or in his house [3]. This is a really important principle because it would permit the use of only one truly efficient wireless communicator for any kind of data transmission (voice and video included), anywhere in the world. The figure presented below, taken from the ITU's web site [4], tries to summarize the general idea behind IMT-2000 and point out its main principles. It is easy to get the standardization procedure's motivations and see what are the driving forces behind ITU's work.

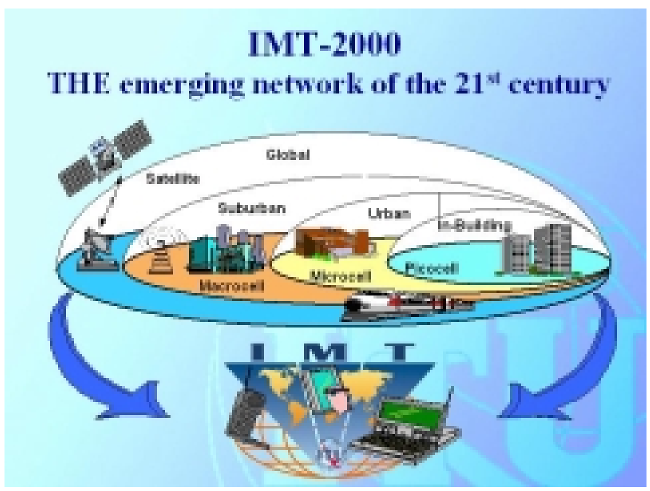


Figure 2 IMT-2000

4. Key features of IMT-2000

A simple word could describe IMT-2000 in the sense of its attempt to provide such a wide range of services so effectively: *challenge*. Challenge for the ITU (mainly ITU-T for the standardization procedure and ITU-R for the radio aspect of it) and its partners (ETSI and others) for the architecture of the system. Challenge also for the different service providers' engineers that have already came up many new ideas, and will hopefully continue to do so, to be able implement such a system. By satisfy all of its principles; IMT-2000 should have the main features listed and described briefly below.

Global System. Standardization allows a high degree of commonality of design while keeping a large variety of systems and terminal types. That, along with the use of international common frequency bands and roaming will allow worldwide marketplace and off-the-shelf compatible equipment thus leading to lower costs.

New services and capabilities. Multimedia transmission is a major component of third-generation systems. It means that they must have the capability to deliver more advanced audio, video and data service on demand. For that reason, minimum data rates have been identified as essential for the proper functioning of the truly multimedia medium. The network must assure full coverage and mobility for 144 Kbps and preferably 384 Kbps as well as a limited one for 2 Mbps. As we've previously said, a 20 Mbps coverage has even been imagined for a second phase of the third generation wireless system. This will be achieved by higher spectrum utilisation efficiency (also leading to lower cost by the employment of flexible radio bearers[1]). Flexibility is also wanted in bandwidth allocation to produce non-symmetrical data transfers potential as well as *bandwidth on demand* (from low-rate paging messages to high bit rates video transmission) capabilities. The idea behind this is that third-generation service provider won't always grant the same bandwidth for every user, it will be adjusted according to the needs of a given transmission; in other word, the bandwidth will be allocated dynamically. All the previous constituents will work together to provide high service quality and integrity (close to the actual fixed networks). Actually, IMT-2000 aims at providing services identical, or similar, to those offered by the fixed networks and in fact, a lot of its supplementary services would directly be derived from those in the fixed network.

Improved security. A particular attention must be given to security issues in order for IMT-2000 to be accepted worldwide as a standard because of its close relation with the national security of each participant country. In order to fully satisfy those given needs, security mechanisms (that will approach that of fixed networks) will be implanted. Security requirements, designed to allow interoperability and roaming will be ensured by: Authentication, Privacy and anonymity, Confidentiality, Integrity, Authorization and access control, Event limitation and Event reporting [3]. Even tough this issue is still being addressed, three typical examples of candidate security mechanisms mainly derived of actual GSM structures can be identified: i) mutual authentication mechanism based on a secret key check function, ii) a unilateral identification mechanism based on digital signature and iii) a unilateral verification mechanism based on a public key scheme.

Evolution and migration. In order to get as much customers as possible, third-generation standards must have flexibility for system evolution i.e. smooth shift from pre-IMT-2000 and within IMT-2000 as well. To the compatibility of services among the IMT-2000 family members, one must add the compatibility with fixed networks and the cohabitation and internetworking with second-generation systems must be included as

[1] A bearer service is a telecommunications service that allows transmission of user-information signals between user-network interfaces.

well. All that means that a modular approach to standardization of IMT-2000 must be followed. In fact, the ITU and its partner has set up global scheme of standardization but *individual operators can select their own evolution path toward IMT-2000 by considering their actual infrastructure, preferred strategies for the introduction of new services and coverage area along with relevant regulatory constraint* [3]. In addition, the modular approach also requires that an open architecture be established to allow easy implementation of new applications as they come.

Multi-Environment Capabilities. Greater coverage, seamless roaming and consistency of service will be provided to users by interworking betweens different networks. This also includes the interaction of satellite and terrestrial networks to provide a true global coverage. The third-generation service may be accessed without any concern with the user density within a certain region (rural Vs urban), its state of movement (fixed or mobile) or its operating environment (including aeronautical and maritime). This necessitates once again a modular structure to allow the networks to start from a simple configuration and grow bigger as needed. That means that software downloadable terminals have to be on hand to support multiband and multi-environment capabilities. It also implies that multi networks must be available within every covered region and also that the optimization of the use of the radio spectrum must be kept in mind at all time. To achieve that, one needs non-static bandwidth, transmission quality and delay that can be all selected depending on the specific application involved and the restrictions of the radio channel used at that particular time. It is also required by the modifications in radio channels' characteristics involved in environmental changes.
One last thing that is involved in the so-called multi-environment capabilities is the possibility to adjust the systems to the need of developing countries to allow them to rapidly introduce basic telecommunication services in a cost effective manner. This would certainly help to bridge the communication gap between the countries and allow the developing ones to be part of the 21st century telecommunications evolution

Summary.
Lower costs. Of course, it is hoped that the standardization procedure will increase the number of handsets throughout the world and thus, decrease their individual cost. Besides, a more accurate use of the spectrum will also decrease the communications' cost for customers.
Worldwide. The integration of fixed structures with wireless (both terrestrial and satellite) ones will enable the birth of a truly global voice, data and multimedia communications network.
Flexibility. The capacity to decide of the best solution for a particular user at a specific time in addition to its capacity for evolution is really a key component of the IMT-2000 wireless communications standard. It is also of great importance to ensure the ability of the standards to support different environments with minimum changes in the technology. Furthermore, since IMT-2000 will be provided for the mass-market it should also be offered in a flexible way so that individual requirements can be met. This requires *really flexible service creation instead of rigidly specified individual services* [3]. In fact, this is probably why the future IMT-2000 operators have identified flexibility as of the utmost importance.

5. Evolution from second generation

The main characteristics of IMT-2000, as a third generation standard, were design to deal with the future requirements of the industry. Naturally, the characteristics that were introduced in it to increase the capabilities of actual standards were first based on those same standards to be able to take advantage of the already implanted features. This was done also to assure the continuity (and compatibility) between the two generations. We present here the main characteristics that have evolved from the second-generation systems in order to fulfil the 21st century requirements and we list few of the technology facilitators in the next section. Here, in order to clarify the key principles of IMT-2000, we intend to make clear how the new standards will differ from the present ones in many important aspects such as frequency bands, data services, roaming capacities, etc.

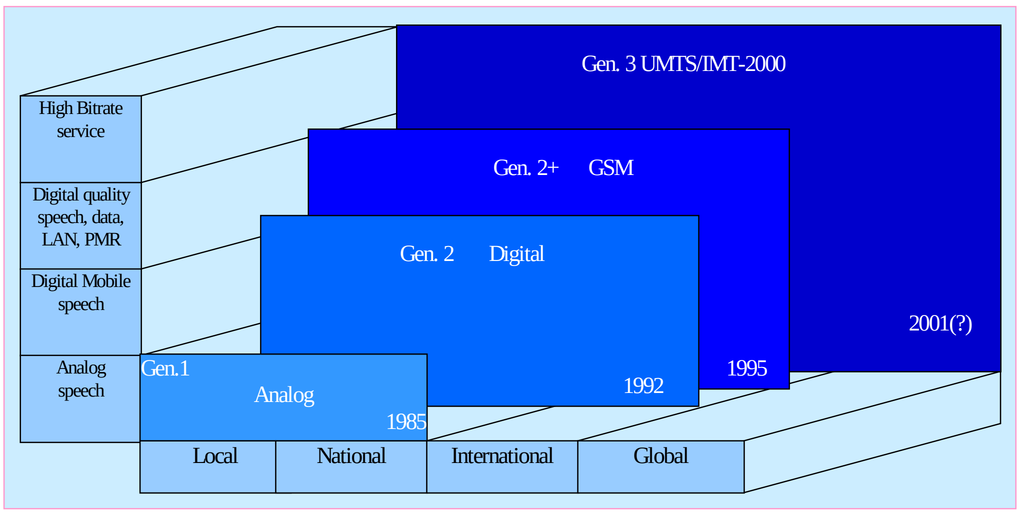


Figure 3 Evolution of wireless systems capacities

Digital Technology. Even tough all second generation standards usage of digital technologies included modulation and speech and channel coding the third generation ones will increase its importance mainly by the addition of programmable radios.

Commonality for different operating environments. While the previous systems were pretty much all designed for specific environments (vehicular or pedestrian for example), one of the key features of the IMT family is, as we've seen, its capacity to *adapt* the use of the same radio interface to different environments among which of course vehicular or pedestrian but also offices, FWA (fixed wireless access) and satellite operation.

Frequency Bands. As we all know the second-generation standards use different frequency bands depending on the region of operation. For example, the European GSM bands are 890-915 *MHz* and 935-960 *MHz*[2] while the North-American standard uses frequency bands around 1.9 *GHz*. In opposition, the IMT-2000 standardization process

[2] The first one is for downlink (mobile to base) and the second one is for uplink (from base to mobile).

truly needed to unify the frequency utilisation. In the WARC-92, common global frequency bands (1.885-2.025 *GHz* and 2.110-2.200 *GHz*) were reserved for FPLMTS (that would eventually become IMT-2000) for both terrestrial and satellite schemes.

Data services. In the past, the data rates achieved with the second generation approaches were limited to 32 or 56 kbps as a maximum. It is almost needless to say it now but the third generation systems intend to supply wideband services (up to 20 Mbps in a future scheme) for pure data transmission as well as for multimedia content. Besides this facility will include circuit- as well as packet-switched network connection.

Roaming. In the preceding operational schemes, subscriber roaming was usually restricted within a specific given boundary in spite of the use of SIM or UIM[3]. As flexibility in migration and multi-environment requires free movement from a region to another, global roaming will certainly be a major issue in upcoming third generation systems. In order to achieve that, the IMT-2000 structures will increase the employment of SIM/UIM and make use of the ITU radio and network interface standards. The accessibility to worldwide satellite coverage will also play an important role in the global roaming.

6. Technology facilitators

The IMT-2000 systems are designed to provide global operation, enhance capabilities and significantly improved performances. Although the objectives for IMT-2000 are very demanding, the required systems and components technologies are either currently available independently or will be shortly. The challenge of the standardization process managed by the ITU is to be able to put together all those technologies and to set up all the necessary infrastructures to form a true 21st century wireless communications global system. Below, we present a list of technologies that should be helpful in the advancement of wireless communications. We introduce those only in an informative way since our intention is not to discuss them but just to present a side aspect implicated in the IMT-2000 standardization process; from this should come out the fact that it is a process that needs a lot of technologies in addition to the *pure wireless* communications ones.

- Satellite component.
- Battery technologies.
- Digital signalling process/integrated circuit (DSP/IC).
- Antenna technologies.
- Software radios.
    - Software radio technologies.
    - Software radio for base stations.
    - Software radio for subscriber terminals.

[3] Subscriber Identity Module and User Identity Module.

UMTS

1. Introduction

With the overwhelming success of the GSM, European countries have really understood the possibilities of a global wireless communications network. This is why since the late 1980s the European Union (EU) has funded an important number of R&D projects (Research of Advanced Communications Technologies in Europe or RACE and Advanced Communication Technologies and Services or ACTS being the two driving forces) leading to the development of future generations of mobile communications concepts, systems and networks [1]. The European version of the ITU's IMT-2000 standard is developed by the European Telecommunications Standards Institute (ETSI) and is called Universal Mobile Telecommunications Systems. UMTS was intended to be a catalyst for increased variety and competition into mobile services, thus giving worthwhile return for a strong support by European research funding of projects creating new technologies and telecommunications applications [9]. This third generation mobile system's standardization procedure has been carried out by the ETSI and it's partner in the third-generation Partnership Project (3GPP). In addition to ETSI, other global standards development organizations (SDOs) have joined the 3GPP among which: The Association of Radio Industries and Business (ARIB), the Committee T1 (T1), the Telecommunications Technology Association (TTA) and the Telecommunications Technology Committee (TTC) and have all agreed to work together for the development of a third generation telecommunications mobile system based on the evolved GSM core networks [1]. Of course, since IMT-2000 aims to be backward compatible, UMTS is developed in order to harmonize the radio access technologies supported by the SDOs. The following figure from [11] symbolizes the 3GPP's partnership.

Figure 4 Third-Generation partnership project

Another truly important issue there is to consider in the evaluation of an upcoming standard is its economical possibilities. One of the principal success factors in third-generation wireless communication systems is the existence of mass market. As we know, UMTS is an evolution of the existing GSM, which is the *de facto* wireless telephone standard in Europe, has over 120 million users worldwide and is available in 120 countries, according to the GSM MoU[4] Association. Therefore, by assuring backward compatibility with GSM, the Universal Mobile Telecommunications System also assure its economical viability.

2. Objectives of UMTS

As we have just said, the ETSI is the organisation responsible for the Universal Mobile Telecommunications System's standardization procedure. Within the European Telecommunications Standards Institute, the Special Mobile Group (SMG) is particularly involve in that process and one of its sub-units, SMG5, is in charge of coordinating the UMTS standardization, of cooperating with European public research projects and of contributing to the ITU-R IMT-2000 work. It means that both ETSI and ITU are really working together to reach the same objectives and thus guarantee internetworking between 3G systems. However, even if UMTS will implement IMT-2000 specifications, it will also complement it with detailed European standards and test specifications. This third-generation standard is planned to support a wider range of service capabilities and recognize more interfaces than IMT-2000 and is intended to be fully compatible with currently existing European Systems such as DECT (cordless), GSM and DCS1800 (cellular) and satellite networks [9]. Nevertheless, the specific European objectives are almost identical to IMT-2000 ones and can be summarized as follow:

- Integration of residential, office and cellular services into one single system based on one piece of low cost user equipment.
- Speech quality comparable to that of fixed networks.
- Low cost services with capability up to multimedia.
- Unique UMTS number independent of country or network and service provider.
- Seamless global radio coverage.
- First planed for radio bearer services up to 144 kbps (preferably 384 kbps) in the beginning and then up to 2 Mbps.
- Flexible radio resource to allow for competition within a frequency band.
- Increased efficiency in the utilization of the spectrum.
- Creation of direct satellite access.
- Use of a new global frequency band.
- Uncompromised security.

It must be pointed out that even though some objectives of the third-generation systems could be implemented within the second-generation ones (such as Global System for Mobile Communications, IS-136 or IS-95), the former are required for full implementation and cost efficiency. As a matter of fact, one of the main objectives of the UMTS standard, global roaming capabilities, could not be totally implemented on the second-generation framework because of the lack of interoperability with other networks [9]. This is why the completion of third-generation standardization is truly required to

[4] Memorandum of Understanding.

fulfil all the ITU's IMT-2000 and ETSI's UMTS requirements. An informative table (**Table 1**) from [8], that presents in a more detailed way the information of Figure 3, is shown below to give a better idea about the evolution from second-generation GSM to third-generation UMTS.

Table 1 Evolution of GSM toward UMTS

	GSM Phase 2	GSM Phase 2+	UMTS
Multiple access	FDMA/TDMA	FDMA/TDMA	TDMA/CDMA
Max Bit-rate	9.6 kbps	64 kbps, 115 kbps	384 kbps, 2 Mbps
Speech quality	Full rate	Enhance full rate, transcoder-free operation	Adaptive multirate
Capacity	900 MHz	Tri-band (900, 1800 and 1900 MHz)	2000 MHz with spectrum efficiency
Roaming	International	Global	Seamless global roaming in multiradio environments and application areas
Security	Authentication, encryption	Fraud information gathering, SS7 security, lawful interception	Enhanced authentication and user identity confidentiality, network domain security
Bearers	Circuit-switched bearers	64 kbps circuit bearer, packet bearers by general packet radio service	Circuit- and packet-switched bearers real-time packet bearer
Services	Speech and low-speed circuit switched data, supplementary services, short message service	Service customization, service portability, value-added services, mobile internet access and web-like information services	Full internet capability, speech data, multimedia, virtual home environment

3. UMTS Radio system

Radio Link

One of the UMTS aspirations is to use a minimum number of radio interfaces to cover a dozen different services and radio operating environments necessary to satisfy the *virtual home* requirement of the third-generation wireless communications systems[5]. Of course the specific demands of each one are quite different and a lot of effort has to be put in their respective development. On the one hand, speech coding has been known for a little bit longer and globally standardized coding schemes (for use from 2 to 64kbps) have been suggested. On the other hand, there is still a lot of work undergoing to find the best suitable candidates for standardized image, video and data codecs as well as other advanced data protocol covering a large portion of the Integral Services Digital Network (ISDN) applications[6].

[5] This is probably why the main focus of the standardization process is on a UMTS radio access network (URAN) that can be connected to one core network.
[6] Please note that some truly efficient coding schemes have been proposed but in all standardization procedures, it takes time for everyone to agree on the one to choose.

In addition to those coding difficulties, for which solutions are on the way, one of the main challenges of UMTS radio system is the dynamic allocation of bandwidth or the *bandwidth on demand*. The major obstacles are the quality of transmission, the efficient use of the spectrum and the internetworking that have to be granted even in presence of delay, errors and outages in radio transmission. Those could create real problems since not all the codecs used ISDN features would be affected in the same way. As an example, the following table (**Table 2** from [9]) summarizes the performance characteristics of some of UMTS bearer service types. As one will realize, flexibility is a required quality of the radio interface since to the complexity of a multiple features service adds up the necessity to provide it in a multi-environment world.

Table 2 Examples of UMTS specific quality of service values

Teleservice	Throughput (Kbps)	Residual Error rate	Delay (ms)
Speech telephony/terrestrial	8 – 32	10E-4	40
Voice data band	2.4 – 64	10E-6	200
Program sound	128	10E-6	200
High quality audio	940	10E-5	200
Video telephony	64 – 384	10E-7	40 – 90
Short message/paging	1.2 – 9.6	10E-6	100
Electronic mail	1.2 – 64	10E-6	100
Telefax (G4)	64	10E-6	100
Broadcast/multicast	1.2 – 9.6	10E-6	100
Public voice announce	8 – 32	10E-4	90
Public A/N announce	1.2 – 9.6	10E-6	100
Unrestricted digital data	64 – 1920	10E-6	100
Database access	2.4 – 768	10E-6	200+
Teleshopping	2.4 – 768	10E-6/10E-7	90
Electronic Newspaper	2.4 – 2000	10E-6	200
Remote control service	1.2 – 9.6	10E-6	100
Location and navigation	64	10E-6	100
Telewriting	32 – 64	10E-6	90

One of the ways to achieve ATM- (Asynchronous Transfer Mode) like radio transmission flexibility is to separate the radio-related functions (RRT), which includes radio link establishment, quality monitoring, data security, error handling and some channel coding, from the actual radio transmission functions. This can be quite complicated because the performance can be compromised by the separation of the initial signal. One proposal is to send an application-independent 80 bits radio packet with each communication to meet the terms of the ATM transmission and the important amount of ISDN applications that UMTS intends to support [9].

Radio system: Satellite aspect

An important constituent of the global roaming aspect of UMTS is the satellite components. As we know the Universal Mobile Telecommunications Systems is required to provide seamless operation in different environments. It will then use pico and micro cells in indoors/urban areas while using macro cells in outdoor and rural areas (see **Figure 2**). Since human presence is not spread over the entire surface of the globe (yet) but mainly because of surface propagation properties at 2 GHz, the UMTS operation band, macro cells will not provide full rural coverage and thus satellite networks will be needed to complete the UTRA (UMTS Terrestrial Radio Access) network. Those should provide a seamless rural outdoor coverage using the IMT satellite frequencies (adjacent to terrestrial ones) with a minimum amount of modifications in services and user terminals. It should also provide handovers between rural and urban networks without any change in the QoS. As we have seen in the past few years, satellite service providers have not been very successful. The main reason for that was probably because of the high prices due to the small number of users combined with the high cost of equipment. It is deeply hoped that the UMTS standardization would allow a cost efficient implementation of satellite networks (or at least cost efficient use of the present ones) resulting from the important increase in the number of users. Such a component would benefit users, of course, but also satellite operators by providing them with new opportunities to approach the emerging massive UMTS user base.

Naturally, there are still problems to solve before we witness the birth of such networks. The first difficulty is the handling of service during the transfer from satellite to terrestrial services (and vice versa). The second is the global traffic routing and charging ($$$) mechanisms issue and the third one is the complexity of frequency sharing between various (and likely competitive) satellite systems. The last but certainly not the least one is the development of cost efficient satellite systems and user terminals, which we still wait for in spite of numerous tries during the past few years.

4. Wideband Code Division Multiple Access

As we have seen, work is currently under way within ETSI to define the European version of the third-generation mobile telecommunications system, known as UMTS or Universal Mobile Telecommunications System, to be introduced in the early years of the 21st century. The main objective of UMTS being to offer an important number of advanced mobile telecommunication services via a variety of public and private network operators in both outdoor and indoor environments. To allow a cost-effective introduction of UMTS, migration/evolution scenarios have been defined within ETSI, aiming at a smooth introduction of the new services and systems, starting from existing contemporary mobile and fixed telecommunication systems. However, since one of the major requests of third-generation standards is to provide high-bit rate multimedia services throughout the network, which necessitates higher bandwidth than is available today, evolution of air interface multiple access is required. A lot of research have been going on in the past few years and it appears that CDMA is the strongest candidate for the third-generation wireless personal communication systems' frequency division duplex. With many R&D projects in the field of wideband CDMA that have taken place in Europe, Japan, the United States, and Korea it seems that wideband CDMA (WCDMA) will have the capabilities to fulfil the requirements of future mobile telecommunication systems [5]. In this section, we will first explain how was WCDMA chosen for FDD and then present its main characteristics. Afterwards, we will briefly compare it with other proposed air interfaces, particularly cdmaOne.

History, Choice of WCDMA

Of course, the main challenges in the development of air interface able to assure third-generation services are technical. But, one must not forget that other factors, such as political and business ones are also at stake. Technical factors include issues such as provision of required data rates and performances while political factors involve reaching agreement between standard bodies and taking into account the different starting points of different countries and regions. On one hand, the investments into the existing systems motivate a backward compatibility approach but on the other, new business opportunities as well as new network requirements might ask for new approaches.

The Japanese Association for Radio Industry and Business (ARIB) was the first to decide, in early 1997, to carry on with detailed standardization of wideband CDMA. This decision by the body responsible for Japan's radio standardization created a technology push that then accelerated the decision making process both in the U.S and Europe. The ETSI was the first to react by joining the Japanese to agree on parameters for wideband CDMA. This harmonized wideband CDMA is now commonly referred as WCDMA. In January 1998, WCDMA was chosen as terrestrial air interface (UTRA) for frequency division duplex (FDD)[7] frequency bands for UMTS. Asian and American GSM operator agreed on WCDMA as well. They also agreed on the choice of time-division CDMA (TD-CDMA) for time-division duplex (TDD)[8]. The United States TIA (Telecommunications Industry Association) was a little bit slower to react but faster to agree and, in December 1997, decided on an IS-95 backward compatible WCDMA. They called their Wideband Code Division Multiple Access's view cdmaOne, which is also referred as cdma2000. Korea, on it side, is still considering two wideband CDMA technologies, one similar to WCDMA and the other similar to cdma2000 (TTA, for Telecommunications Technology Association, II & I respectively) [5]. The following table resumes what has just been said and makes clear the different choices made by the

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[7] Frequency Division Duplex uses two separate frequencies, one for the uplink and one for the downlink communications. This method causes less interference but it requires a pair of separated frequency bands to be allocated which may not be possible since bandwidth is limited in wireless communication.

[8] Time Division Duplex uses the same frequency for uplink and downlink communications. The two ends take turns to transmit and hence the subscriber and base station must agree upon the timeslot for uplink and downlink transmission. Since we want to focus more on WCDMA, we will not discuss much about TDD…

diverse standardizations bodies [7]. We also present a figure (from [6]) that summarizes the relation between the different air interfaces proposed for IMT-2000.

Table 3 Summary of air interface choices for 3rd generation systems

Mode	Title	Origin	Supporters
1	IMT Direct Spread WCDMA & TTA II FDD	Based on the first operational mode of ETSI's UTRA (3G Terrestrial Radio Access) RTT proposal.	Japan's ARIB and GSM network operators and vendors. To be deployed in Japan and Europe and TTA II in Korea.
2	IMT Multi-Carrier cdma2000 & TTA II FDD	Based on the cdma2000 RTT proposal from the US Telecommunications Industry Association (TIA). Consists of the RTT1X and RTT3X components	CdmaOne operators and members of the CDMA Development Group (CDG). Likely to be deployed in the USA and possibly TTA I in Korea.

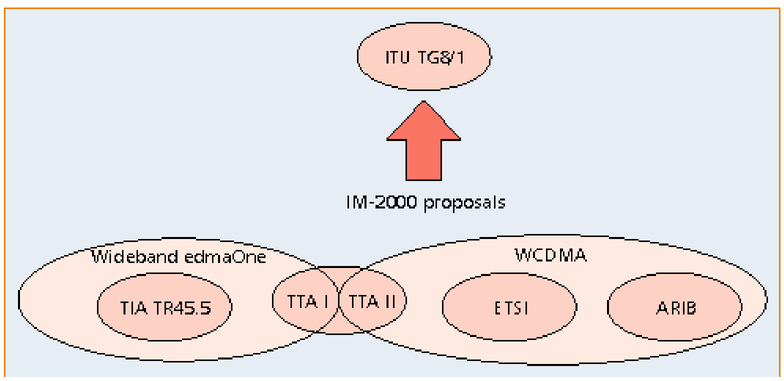

Figure 5 Relationship between WCDMA schemes and standardisation bodies.

WCDMA Specifications for Frequency Division Duplex radio access

In CDMA each user is assigned a unique code sequence it uses to encode its information-bearing signal. The receiver, identifying the code sequences of the user, decodes the received signal after reception and recovers the original data. This is made possible by the fact that the correlation between the code of the desired user and the codes of others is small. Since the bandwidth of the code signal is chosen to be much larger than the bandwidth of the information-bearing signal[9], the encoding process enlarges (spreads) the spectrum of the signal and is therefore also known as spread-spectrum modulation. The resulting signal is also called a spread-spectrum signal, and this is why CDMA is often denoted as spread-spectrum multiple access (SSMA).

In the development of the third generation air interface, two different CDMA-based network types have been imagined. In WCDMA (and TTA II), and thus in UMTS, network asynchronous scheme is used while a synchronous one has been proposed for

[9] This was first introduces in military applications to prevent jamming.

cdmaOne[10]. In the first one, the base stations are obviously not synchronized whereas they are within a few microseconds in the second one. The WCDMA scheme has been developed from the FMA2 scheme in Europe and the ARIB's WCDMA from the Core-A system in Japan. As the WCDMA scheme has been developed as a joint effort between ETSI and ARIB, the uplink of the WCDMA plan is based mainly on the FMA2 scheme, and the downlink on the Core-A format.

Evaluated in comparison with second-generation CDMA, the UMTS's WCDMA technology introduce new capabilities. Even if we won't go thru all the GSM main characteristics, please keep in mind that the handover between the WCDMA and GSM systems has been one of the main design criteria taken into account in the WCDMA frame timing definition. By keeping the main 120ms superframe structure, engineers have ensured compatibility among them [5]. In the next pages, we present the main features and capabilities of WCDMA[11] and highlight the most important differences with the second-generation CDMA systems as well as those encountered with cdmaOne.

Bandwidth. To achieve the very high data rates, WCDMA requires a wide frequency band around 5MHz of high capacity with 50-80 voice channels (per 5 MHz carrier) compare with 8 channels per 200 kHz carrier for GSM. The choice is motivated by the necessity to balance the high data rate demand of third-generation systems with the scarcity of the bandwidth. With 5 MHz, 144 and 384 kbps data rates can be achieved easily while 2 Mbps peak rate can be provided under specific conditions. The actual requirements are that data-delivery rates will start at 144 kbps within a 35km radius of a base station with fast mobile station speed while the rates will reach 384 kbps within a 1 km base-station radius at speeds to 100 km/hour. Indoors, it will be possible to get more than 2 Mbps within a 100 m radius from the base-station and a mobile speed of 10 km/hour. Another reason to choose the large 5 MHz bandwidth is that it can resolve more multipaths than narrower bandwidths, increasing diversity and thus improving performance. Be aware that, in the meantime, WCDMA provides higher capacity and increased coverage: up to eight times more traffic per carrier compared to a narrowband CDMA carrier. This is achieved by up to 100% better usage of the frequency spectrum, which is necessary to allow such a *spreading* spread-spectrum given the shortage of the bandwidth, and, as we know, the present cost of every single frequency band [5]. Note that larger data rates, up to 20 Mbps, have been proposed to provide higher data rates but won't be implemented in the first phase of that third-generation system; in fact, one might have to wait for the fourth-generation for such a high bit rate to be made available.

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[10] We discuss only the different option for frequency division duplex here since those are the ones for which most of the work has been done on.

[11] By doing do, we intend to give accurate characteristics of the WCDMA scheme developed for UMTS. Although since it is an evolving standard, some specifications might have been reviewed within 3GPP.

Chip Rate. In direct sequence CDMA, multiple simultaneous transmissions are separated using codes. Each bit time is subdivided into *m* short intervals called *chips* (e.g. 64 or 128 chips per bit). Each station is assigned a unique *m*-bit chip sequence (i.e. code), which is used to distinguish itself from others. This is achieved by ensuring all chip sequences are pairwise orthogonal (i.e. the inner product of any two distinct chip sequence is 0). The choice of the chip rate (CR) is made upon few parameters such as spectrum deployment scenarios, dual mode terminal implementation and, of course, maximum data rate desired. A relation between CR, pulse shaping roll-off factor (α) and channel separation can also be drawn. One can design a system such as two adjacent channel spectra don't overlap, which would be better if there can be high power-level differences between adjacent carriers. However, in microcells, where the same antenna masts are used for two adjacent carriers, it can be better to allow power leaks from one carrier to another by permitting overlapping of two adjacent spectra. For example, in WCDMA, where the CR was first set to 4.096 Mchips/s mainly for backward compatibility with GSM, if raised cosine filtering was used, the minimum channel separation ($= CR/2*(1+\alpha)$) would have been 4.99712 MHz [5]. Note that the CR has now been relaxed to 3.84 Mchips/s in order to simplify the development of the RF part of multimode terminals (DS and Multi Carrier FDD, TDD), where the chip rate of the MC component ensures backward compatibility for IS-95 operators.

Uplink and Downlink Channels. In the definition of the logical channels for WCDMA, ETSI and ARIB have followed the ITU Recommendations. They have defined the logical channels presented below; the first three being available common control channels while the following two are the dedicated channels i.e. the ones carrying the information [6]. In the study of the channels structure, it must be kept in mind that WCDMA has two frequency bands allocated: one for sending data from the terminal and one for receiving data on the terminal. This technique is called symmetric which means that the same amount of radio resources is needed in the uplink and downlink. Here are the so-defined logical channels:

- Broadcast control channel (BCCH) carries system and cell specific information (DL).
- Paging channel (PCH) for messages to the mobiles in the paging area (DL).
- Forward access channel (FACH) for messages from the base station to the mobile in one cell (UL).
- Dedicated control channel (DCCH) covers the two dedicated control channel stand-alone dedicated channel (SDCCH) and associated control channel (ACCH) (UL/DL).
- Dedicated traffic channel (DTCH) for point-to-point data transmission in the uplink and downlink (UL/DL).

There are two dedicated channels and one common channel in the uplink (from base to mobile). User data is transmitted on the dedicated physical data channel (DPDCH), which is I/Q modulated with the control information that is sent out on the dedicated physical control channel (DPCCH). The later being needed to transmit pilot symbols for coherent reception, power control signalling bits, and rate information for rate detection while the DPDCH carries the information that one is willing to transmit (user data). Time-multiplexed pilot symbols are used in the uplink of WCDMA to perform coherent detection. In comparison with second-generation CDMA approaches, that use non-coherent detection, the addition of the pilot will increase the performance of the uplink by a factor depending on the proportion of pilot signal power to data signal power. In fact, this improvement can generally be estimated around 3dB, which is a factor of great importance in wireless communications. **Figure 6** (from [6]) gives a good idea of what the WCDMA uplink's dedicated channels are made of. WCDMA then uses a combined I/Q and code multiplexing solution (dual-channel QPSK) for multiplexing the DPDCH with the DPCCH to avoid electromagnetic compatibility (EMC) problems with discontinuous transmission (DTX).

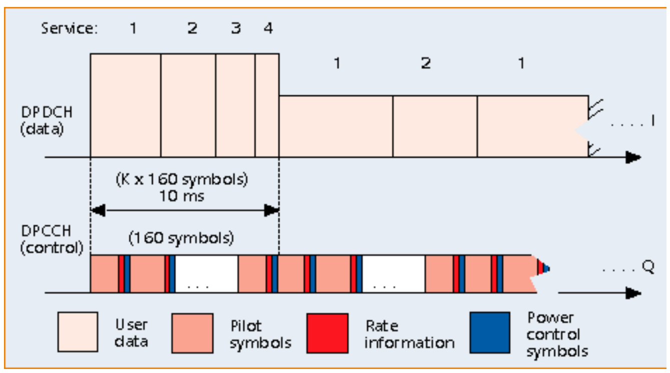

Figure 6 WCDMA uplink multirate transmission

In the downlink (mobile to base) three common physical channels are exploited: the primary and secondary common control physical channels (CCPCH) carry the downlink common control logical channels (BCCH and PCH) while the synchronization channel (SCH) (see **Figure 7**, from [6]) provides timing information and is used for handover measurements by the mobile station. The dedicated channels (DPDCH and DPCCH) are time multiplexed and so are the pilot symbols that are primary used for coherent detection. Since they are user-dedicated, i.e. they have to take the same path as the data signal; they can be used for channel estimation, even with adaptive antennas beamforming. In addition, fast power control is used in the downlink to improve its transmission performance in two ways: first, it decreases effects of multipaths fading channel; second, it increases the multi-user interference variable within the cell since the orthogonality between users is imperfect due to the multipaths channel [5] & [6]. Note that *pure* QPSK is used in the downlink opposition to dual-channel QPSK in the uplink.

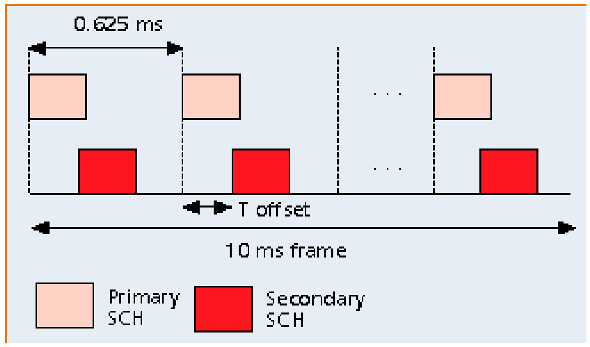

Figure 7 Synchronization channels in the downlink

Spreading and modulation Solutions. WCDMA uses different spreading codes for cell separation in the downlink and user separation in the uplink. In fact, the FDD component applies a two-layered code structure consisting of spreading codes and scrambling codes. In the uplink, the spreading codes are first applied to each transmission to distinguish different mobile stations and then the DPDCH and DPCCH are QPSK modulated. In the downlink, spreading is performed by channelization codes for each DPCH depending on the transmission service required. Afterwards, a cell specific scrambling code is applied to distinguish different cells. The data modulation used is also QPSK. Orthogonal variable spreading factor (OVSF) codes are employed for the spreading codes, in order to preserve the orthogonality between different rates and spreading factors in both uplink and downlink.

In the downlink, Gold codes[12] of length 2^{18} are used, but they are truncated to form a cycle of a 10ms frame and either short or long spreading (scrambling codes) are used in the uplink. The code lengths are limited to minimize cell search time and thus facilitate the implementation of multiuser receiver techniques. The air interface of UMTS uses a synchronization channel masked with an orthogonal short Gold code of length 256 chips spanning over one symbol. The short codes are used to ease the implementation of advanced multiuser receiver techniques; otherwise long spreading codes can be used. Short codes are VL-Kasami codes of length 256 and long codes are Gold sequences of length 2^{41}. However, as we have said, the latter are truncated to form a cycle of a 10-ms frame.

[12] In spread-spectrum systems, a Gold code is a code that is generated by summing, using modulo-two addition, the outputs of two spread-spectrum code-sequence generators.

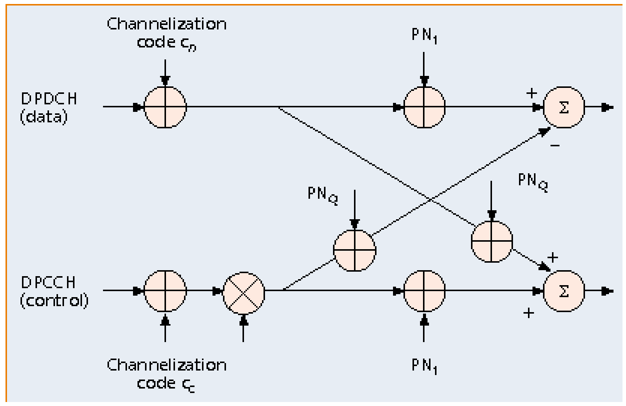

Figure 8 Complex Spreading

As we have seen, the data modulation used by the UMTS FDD air interface is QPSK both for the uplink and downlink. The choice of those coding schemes leads to parallel transmission of two channels since the In Phase/Quadrature (I/Q) multiplexing is used. For that reason, attention must be paid to modulated signal constellation and related peak-to-average power ratio. By the use of the complex spreading circuit propose for WCDMA shown in **Figure 8**, the peak-to-average power is limited and consequently the power efficiency improved [5].

Multirate. Multirating is the multiplexing of multiple services of the same connection on one Dedicated Physical Data Channel (DPDCH) or the multiplexing of several connections of different QoS requirements on the same DPDCH. Multirate is necessary to provide flexible data rates which is of great importance since the bandwidth need to be allocated only on demand primary because of its scarcity but also because it needs to be provided if demanded. The general WCDMA strategy is to use a single code transmission for small data rates and multicode for higher ones.

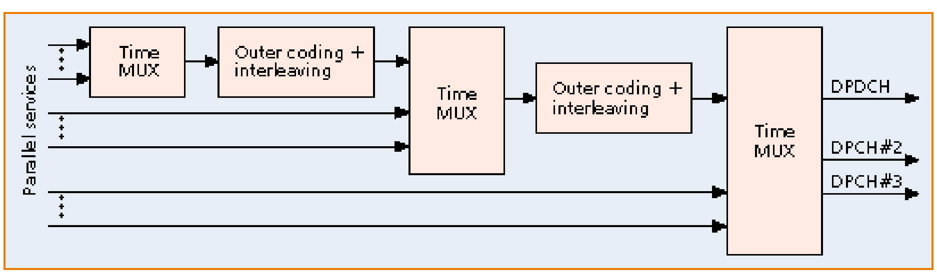

Figure 9 Service Multiplexing in WCDMA

If we are dealing with two services involved in the same transmission (like speech and video in video-conferencing for example), time multiplexing can be used either before or after the inner or outer coding, as illustrated in **Figure 8** [6]. After service multiplexing and channel coding, the multiservice data stream is mapped to one DPDCH. Since the total bit rate can be almost arbitrary it is necessary to permit the service provider to allocate several DPDCHs if the total rate exceeds the upper limit for single code transmission. The main advantage of this first technique is that time multiplexing avoids multicode transmission thus reducing peak-to-average power of transmission.

In a second scheme, in the case where we are dealing with multiple transmissions at the same time, parallel services could be mapped to different DPDCHs using multicode coding/interleaving of distinct channels. With this alternative scheme, the power requirement but also the QoS of each channel, can be separately and independently controlled. The drawback of code multiplexing is obviously the need for multicode transmission, which will increase mobile station complexity, set higher requirements for the power amplifier linearity in transmission, and finally ask for more correlators in reception. Different coding schemes are under investigation depending on the bit error rate (BER) and delay requirements of different services. As examples, we list here some coding possibility: For services with a BER of 10^{-3}, convolutional coding of 1/3 is used for relatively low bit rate and convolutional coding of 1/2 for higher bit. For higher quality service, up to the 10^{-6} BER level classes, outer Reed-Solomon coding can be used and turbo codes have also been proposed for transmissions with bit rate higher than 32 kbps [5].

In summary, a certain multirate scheme is first chosen to suit the particular needs of the different transmissions involve in a communication resulting in the use of one or several DPDCHs. Then each transmission is assigned a particular spreading code selected to distinguish the actual mobile station from the others. After that, each of the several transmissions is time/code multiplex on its assigned DPDCH before the later is QPSK modulated with the corresponding dedicated control channel.

Handover. As we have stated previously, in the IMT-2000's vision and thus in UMTS as well, the global roaming is a key issue. Therefore, WCDMA must include certain specifications permitting to achieve it. The first thing to consider is the structure of WCDMA asynchronous[13] base stations since this type of base stations must be considered when designing soft handover algorithms. The second aspect, interfrequency handover, regards the utilisation of hierarchical cell structures (HCHs), which is one important concept of third-generation systems as shown in **Figure 2**.

In order to enter soft handover, the observed timing differences of the downlink synchronization channels (from the two base stations) are measured by the mobile station, which then reports it to its present base station. The later is therefore able to adjust the timing of the new downlink soft handover connection with a resolution of one symbol. That enables the mobile RAKE receiver[14] to collect the macro diversity energy

[13] Asynchronous base stations don't need to be synchronized, and therefore, don't require any external source of synchronization.
[14] A receiver technique which uses several baseband correlators to individually process several signal multipath components. The correlator outputs are combined to achieve improved communications reliability and performance [10].

from the two base stations and then achieve the timing adjustments of dedicated downlink channels without losing orthogonality of downlink codes but still reaching a resolution of one symbol [6].

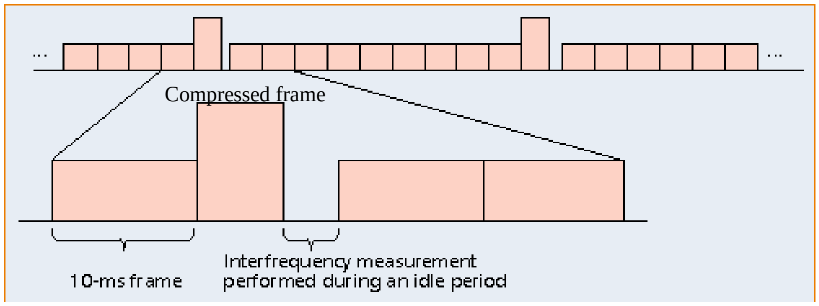

Figure 10 Slotted mode structure

The second aspect, i.e. interfrequency handover, is needed for utilization of hierarchical cell structures (macro, micro, and pico cells) since the cells belonging to different layers will be using different frequencies. Several carriers and interfrequency handovers may also be used for taking care of high capacity needs in hot spots as well as to provide handovers with second-generation systems, like GSM in Europe or IS-95 in the U.S. A key requirement for seamless interfrequency handover is the ability of the mobile station (the handset) to carry out cell search on a carrier's frequency different from the current one without affecting ordinary data flow [5]. Various methods for making measurements on other frequencies while still having the connection running on the current frequency are considered for interfrequency measurements in WCDMA. The first approach, dual receiver, is considered suitable for mobile stations with receiver diversity. The concept is to temporarily reallocate one of the receiver branches for measurements on a different carrier while the other keeps receiving from the current frequency. The main advantage of the dual receiver technique is that there is no break in the current frequency connection. The second idea, the slotted mode, is presented in **Figure 10** (from [6]). This approach is proposed for single-receiver mobile stations (no antenna diversity) to allow interfrequency measurements for interfrequency handover. The information normally transmitted during a 10-ms frame is compressed in time (either by code puncturing or by changing the forward error correction's rate) thus leaving unused time for the mobile station to perform measurements on other frequencies [5] & [6].

Multiuser detection. Second generation CDMA receivers, based on the RAKE receiver principle, are interference limited because they consider other users' signals as interference. In practice this means that when a new user, or interferer, enters the network, other users' service quality can go below the acceptable level. Optimally, all signals would be detected jointly or interference from other signals would be removed by subtracting them from the desired signal. That would enhance the network interference resistance thus boosting the number of users who can be served at the same time.

Multiuser detection (MUD), also called joint detection and interference cancellation (IC), provides a means of reducing the effect of multiple access interference, and hence increases the system capacity [6]. In addition to capacity improvement, MUD alleviates the near/far problem typical to DS-CDMA systems. If a user's mobile station is too close to the base station it may block the whole cell traffic by using too high transmission power which would result in high level interference for others. However, if this user is previously detected and his signal subtracted from their input signal, the other users won't see any interference. This summarizes the basic concept of multiuser detection principle.

Such a strategy is quite simple to implement on system using short spreading codes since cross-correlation between different users' signal does not change every symbol as with long ones. As we have seen, WCDMA uses long spreading codes and that makes it much more complicated to employ MUD in UMTS's air interface. The most feasible approach that has been proposed is the *regenerative parallel interference cancellation algorithms*. This technique consists in carrying out the interference cancellation at the chip level and, in that way, avoiding explicit calculation of cross-correlation between spreading codes from different mobile stations [6], which is computationally very expensive. Complexity issues, in addition with stations' differences, impose that there must be different way of using MUD in the uplink and the downlink. Base stations have to demodulate the signal of all users while mobile stations only have to take care of one single signal. For that reason, a simpler interference suppression scheme can be used in the mobile stations than the one used in the base stations [5].

Packet data. WCDMA uses two different strategies for data packet transmission. The first one, called *common channel packet transmission*, is used for short infrequent packet. The idea is to add short data packets directly to a random access burst which is 10 ms long and transmitted with fixed power, which is based on the slotted Aloha scheme[15], in order to avoid having to maintain a dedicated channel where there is no real point to do so. In the meantime, the delay associated with a transfer to a dedicated channel is avoided. Taken from [6], **Figure 11** illustrates packet transmission on a common channel.

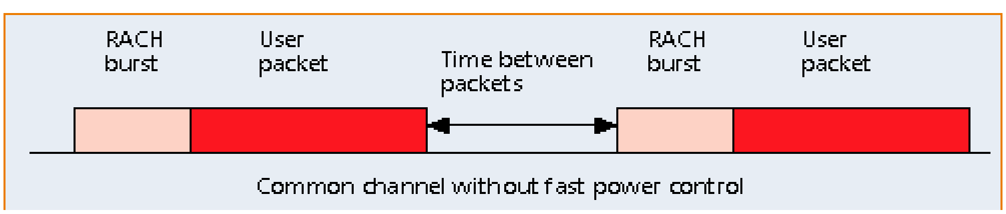

Figure 11 Packet transmission on the common channel.

[15] Aloha scheme, also called the *Aloha method* refers to a simple communications scheme in which each source (transmitter) in a network sends data whenever there is a frame to send. If the frame successfully reaches the destination (receiver), the next frame is sent.

The second strategy is used to send more frequent packets thru a dedicated channel. For large unique packet, a *single-packet scheme* is used. The channel is reserved only for the packet transmission duration and release immediately afterwards. If some packets need to be transmitted more often, a *multipacket scheme* can be used. For that option, the dedicated channel is maintained by transmitting power control and synchronization information between subsequent packets [5].

Differences between WCDMA and cdmaOne

In order to highlight the main characteristics of cdmaOne, also know as cdma2000, we list its principal features in comparison with the WCDMA scheme in Table 4. The purpose here is to point out the fact that there are different technical ways to achieve the same goal for third generation wireless communications systems. The WCDMA is the evolution of the European GSM while the cdmaOne represents the American future.

Table 4 WCDMA Vs cdmaOne

	WCDMA	cdmaOne
Channel bandwidth	1.25, 5, 10, 20 MHz	1.25, 5, 10, 15, 20 MHz
Downlink RF channel structure	Direct spread	Direct spread or multicarrier
Chip rate	3.84 Mchips/s	3.6864 Mchips/s for direct spread *n* x 1.2288 Mchips/s (*n* = 1, 3, 6, 9, 12) for multicarrier
Roll-off factor for chip shaping	0.22	Similar to IS-95
Frame length	10 ms, 20 ms (optional)	20 ms for data and control/5 ms for control information on the fundamental and dedicated control channel
Spreading modulation	Balanced QPSK (downlink) Dual channel QPSK (uplink) Complex spreading circuit	Balanced QPSK (downlink) Dual-channel QPSK (uplink) Complex spreading circuit
Data modulation	QPSK	QPSK
Coherent detection	User dedicated time multiplexed pilot (downlink and uplink); no common pilot in downlink	Pilot time multiplexed with PC and EIB (uplink) Common continuous pilot channel and auxiliary pilot (downlink)
Channel multiplexing in uplink	Control and pilot channel time multiplexed I&Q multiplexing for data and control channel	Control, pilot, fundamental, and supplemental code multiplexed I&Q multiplexing for data and control channels
Multirate	Variable spreading and multicode	Variable spreading and multicode

Spreading factors	4-256 (3.84 Mchips/s)	4-256 (3.6864 Mchips/s)
Power control	Open and fast closed loop (1.6 kHz)	Open loop and fast closed loop (800 Hz, higher rates under study)
Spreading (downlink)	Variable length orthogonal sequences for channel separation Gold sequences 2^{18} for cell and user separation (truncated cycle 10 ms)	Variable length Walsh sequences for channel separation, M-sequence 2^{15} (same sequence with time shift utilized in different cells, different sequence in I&Q channel)
Spreading (uplink)	Variable length orthogonal sequences for channel separation, Gold sequence 2^{41} for user separation (different time shifts in I and Q channel, truncated cycle 10 ms)	Variable length orthogonal sequences for channel separation, M-sequence 2^{15} (same sequence for all users, different sequences in I&Q channels); M-sequence 2^{41}1 for user separation (different time shifts for different users)
Handover	Soft handover Interfrequency handover	Soft handover Interfrequency handover

TDMA and OFDM based schemes

In addition to WCDMA and cdmaOne, other schemes have been proposed in order to carry out the requirements of UMTS. The first one is orthogonal frequency-division multiplexing (OFDM) designs have been proposed for UMTS air interface for two main reasons: its flexibility and its easy equalization. OFDM is a method of digital modulation in which a signal is split into several narrowband channels at different frequencies. The difference between OFDM and other FDD systems lies in the way in which the signals are modulated and demodulated. Priority is given to minimizing the interference, or crosstalk, among the channels and symbols comprising the data stream. Less importance is placed on perfecting individual channels. The main drawback of OFDM is the high peak-to-average power, which is of main importance for mobile station as well as in long-range applications. Work is still underway to develop coding methods to overcome this problem [5].

The second one, and perhaps the most plausible alternative, is Time Division Multiple Access (TDMA). This scheme divides each cellular channel into three time slots in order to increase the amount of data that can be carried. It has come out to be part of the third generation era as a natural evolution of the present IS-136 standard. It has also been considered as an evolution of GSM in the Enhance Data GSM Environment (EDGE) project. However, some companies seem to give up EDGE to work on CDMA schemes for UMTS and are thus turning toward WCDMA systems. Besides, TDMA systems, that had first been proposed for Time Division Duplex, has been replace by the radio access technique formerly proposed by TD-CDMA thus leaving all the room to CDMA-based schemes in the European version of third-generation wireless communications systems.

Conclusion

We reviewed here the main aspects of the standardization process leading to third-generation wireless communications systems. As we have realized, this procedure, both at ITU and ETSI levels, is necessary to provide common ground to competitive companies to reach consensus. With that in mind, we have attempted to highlight that aspect in the presentation of the history of IMT-2000 and its principal objectives and features. We have seen how the European Telecommunications Standards Institute and its partners in the 3GPP have planned the future of European wireless communication and how UMTS intends to fulfill the *virtual home environment* requirement. We have presented the main concept of its radio link and tried to make the principal characteristics of its air interface clear. The approach we have chosen in our presentation of UMTS was meant to emphasize on the fact that it will bring a large new range of possibilities that will change the way we see and use telecommunications and that should allow third-generation wireless systems to slowly, but surely, supplant the present fixed networks.

As one will have understood, even if work is still on the way, a lot of efforts have already been made in order to provide the global seamless coverage for high quality and user-friendly services, ranging from low bit rate data and speech to video and other multimedia applications. It means that what was considered, a decade ago, as very futuristic visions are now technologically accessible. Third-generation wireless telecommunications systems will provide communications anywhere, anytime in any form and help shrinking our world to form a global village. Now, we have to go beyond the limits of our imagination to think about revolutionary technologies in order to foresee what the next generations of wireless communications will be like and what are the new capabilities they will bring. As the head of the Nokia company’s research centre has once said [12]: *only the fundamental laws of physics will put limits to the evolution of wireless communications*…

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