The Evolution of Third-Generation Cellular Standards

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Index words: cellular, wireless, standard, generation, radio

ABSTRACT

This paper provides an overview of the evolutionary path of mobile/terrestrial cellular standards, leading up to the now defined third-generation cellular standards.

Commercial mobile cellular systems first became available in the early 1980's. These first systems were deployed, utilizing analog technology over circuit-switched networks. They had very limited features, poor voice quality, and limited radio coverage, although they have vastly improved over the last two decades and are still widely deployed around the world. In addition, data transfer was limited to 9600 baud.

In the early 1990's, the second generation of mobile cellular systems was introduced. Based upon digital technology and still utilizing the circuit-switched network, new features and services were introduced. Speech quality, although not equivalent to that of analog, was digitized through a low 8kbps bitrate vocoder that used Code Excited Linear Projection (CELP) technology. This has also been enhanced, over the past five years, to the extent that speech quality now exceeds that of the FM analog systems.

The immediate motivating factor for the third-generation communications systems is to increase system capacity. The overall number of users is exceeding the radio spectrum allocated to the second-generation; however, receiving and sending data are the essential building blocks to widespread mobile Internet access and to mobile data transfer, capabilities enabled with the third-generation. The third-generation is a generic term used for the next generation of mobile communications systems, often referred to simply as "3G." 3G mobile systems will provide enhanced services such as voice, text, and high-speed data, with 144kbps as an overall goal. The technology involved in the deployment of 3G systems and services is currently under development throughout the industry.

Attaining the goals of 3G will be an evolutionary migration from the installed 2G systems. Operators are phasing in new enhanced 2G capabilities, preparing for 3G services, and attempting to provide a seamless transition from existing digital systems, including full backwards compatibility. From a consumer perspective, this integration of system and service profiles, along with multi-mode terminals will mean worldwide roaming possibilities. 3G systems offer up to fifteen times the network capacity of analog networks. With the initial third-generation networks due to be launched in Japan in early 2001, and with European countries following in early 2002, 3G is already in sight. To enable third-generation capabilities, especially worldwide roaming, the radio interface specifications need to be defined and adopted, and complete interoperability needs to be finalized.

INTRODUCTION

While no one can predict the future, it is certain that the way we communicate in the future will be vastly different from today. Video-on-demand, high-speed multimedia, and mobile Internet are just a few of the communication possibilities. Third-generation systems will expand the possibilities of information transfer and communication. "Third Generation" is a term given to wireless services that, for example, allow users to make video calls from a mobile terminal, while simultaneously accessing a remote database, or while receiving e-mails and phone calls. The foundation for these services has already been laid in the existing structure of today's digital mobile phone networks. What is needed in order to support these advanced multimedia services is to expand the information capacity, or "bandwidth" of the wireless links.

While conversational speech is still the main service of today's mobile systems, support for the data communications over-the-air interface is quickly increasing. To implement this capability for the market, radio interface standards must be defined and adopted worldwide. The process of developing these standards has taken years of effort by hundreds of participating companies and government agencies around the world. The First-Generation (1G) systems used analog technology. The current handsets, widely deployed today, use Second-Generation (2G) technology, often referred to as "digital." The Third-Generation systems extend the voice-only digital from 2G (as enhanced), and incorporate additional data capability. During the transition from 2G to 3G there will be an interim deployment of 2.5G digital technology with limited data capabilities, such as short messaging services (ability to send and receive short text messages from a cellular system).

The process of developing standards provides independent companies with an opportunity to influence the standards in such a way that their respective Intellectual Property Rights (IPR's) will be adopted. This process also provides companies insight into the future direction of communications, and it gives them information that allows them to prepare for and to make advanced engineering and marketing decisions.

Developing international standards to which all participating members can agree requires a good deal of time, study, and patience. The process is slow and is consensus-driven. This paper addresses the Mobile/Cellular Standards process, highlights the key Standards Organizations, and provides an overview of the 3G Radio Interface Standards (see Figure 1).

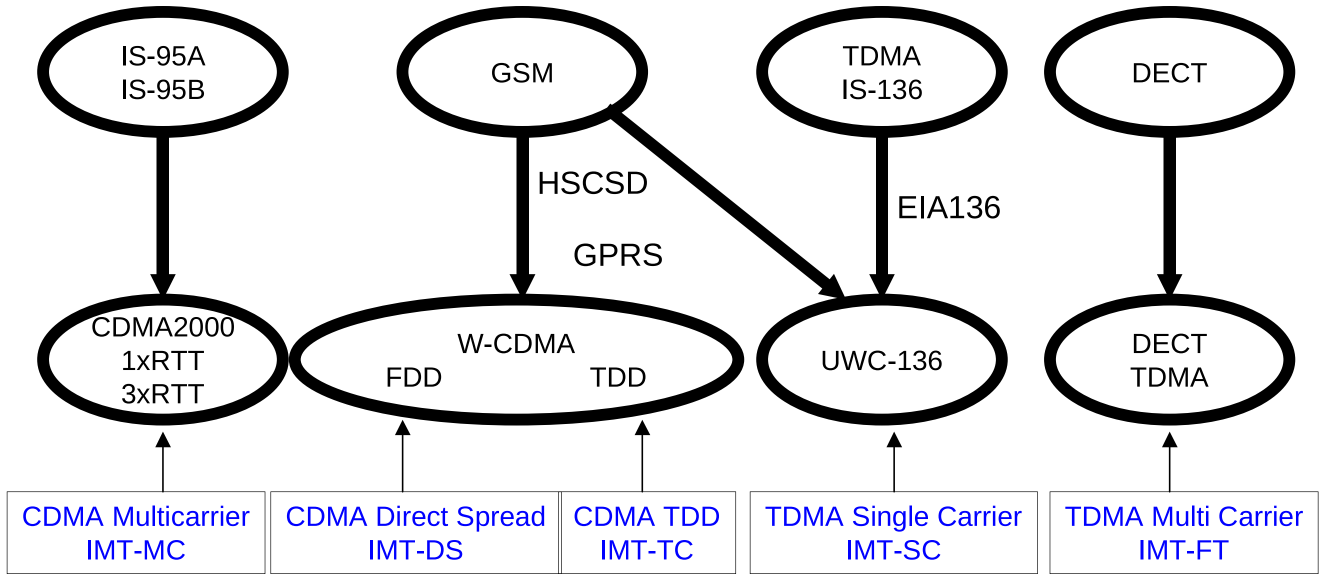

Figure 1: The evolution of mobile cellular standards

MOBILE/CELLULAR STANDARDS PROCESS

The standards organizations and partnership projects provide technical input to the global standards developer for ratification and approval.

The International Telecommunications Union (ITU), a charter organization of the United Nations, is the pre-eminent global standards developer for telecommunications. The ITU-R (radio communications sector) addresses terrestrial and space (satellite) radio communication. Standards development organizations and partnership projects, listed below, provide technical input to the ITU for ratification and approval.

Standards Development Organizations

Standards development organizations (SDOs) are national or multi-national organizations, actively involved in defining the next-generation wireless standards, along with refining the ongoing remedial editing of existing standards SDOs are comprised of various companies who work together to promote specification proposals. SDOs also study radio spectrum utilization, including such subsets as intersystem issues, emergency services, and accommodations for the disabled. They also coordinate and cooperate with the ITU on standardization of radio systems in the field of telecommunications. The coordination and cooperation issues are managed by "Harmonization" groups. The following is a list of Western standard development organizations, along with their respective areas of geographical and technical interests:

- The European Telecommunications Standards Institute (ETSI) is defining a technology standard for 3G called the Universal Mobile Telecommunications Systems (UMTS).
- The Japan Association of Radio Industries and Business (ARIB) primarily focuses on WCDMA for IMT-2000.

- The primary Canadian SDO is the Telecommunications Standards Advisory Council of Canada (TSACC).
- The American National Standards Institute (ANSI) is a US repository for standards considered to be semi-permanent, a nebulous term for “longer than interim.”
- The United States Telecommunications Industry Association (TIA) and T1 have presented several technology proposals on WCDMA, TDMA UWC-136 (based upon D-AMPS IS-136), and cdma2000 (based upon IS-95). The American National Standards Institute (ANSI) accredits both TIA and T1. The primary standards working groups are TR45 (Mobile & Personal Communications 900 & 1800 Standards and TR46 (Mobile & Personal Communications 1800 only Standards).

The Asian standards development organizations include the Korean Telecommunications Technology Association (TTA) and China Wireless Telecommunications Standards Group (CWTS), Partnership Projects.

The Third-Generation Partnership Project (3GPP) was formed by SDOs and other related standards’ bodies to harmonize European, Asian, and North American standards proposals, and to define a complete set of global technical specifications for third-generation mobile systems based upon the evolved GSM core networks and radio access technologies. The project is better known as “3GPP.”

3GPP is comprised of the following SDOs: ARIB (Japan), CWTS (China), ETSI (Europe), T1 (USA), and TTA (Korea). The project is divided into several technical specification groups (TSG’s), with each TSG having multiple working groups, each responsible for defining an aspect of the third-generation standard. 3GPP is chartered to define the radio access network, the core network (including mobility management and global roaming), terminal access to the network (including specifications for the user identification module), and systems and services. (Additional information is available at the 3GPP web site *http://www.3gpp.org*.

The Third-Generation Partnership Project 2 (3GPP2) was organized by the SDOs that were concentrating on the development and evolution of the American National Standard (ANSI/TIA-41 core networks) and the relevant radio access technologies. The five SDOs are ARIB (Japan), CWTS (China), TIA (USA), TTA (Korea), and TTC (Japan). Similar to 3GPP, 3GPP2 is also comprised of several technical specification groups, each with multiple working groups. (Additional information is available at the 3GPP2 web site *http://www.3gpp2.org*.)

Both 3GPP and 3GPP2 organizations recognize the ITU as the preeminent organization for international telecommunications standardization, and they have agreed to submit all results to the ITU for consideration and approval.

THE MIGRATION TO 3G

The genesis of today’s wireless technology began in the early 1980’s with the introduction of the first mobile cellular handsets. These systems utilized analog interface technology and supported voice-only capabilities. This technology is still used in many parts of the world; however, it is limited in bandwidth and is low in quality. With the high demand for cell phones and the increased need for enhanced quality and more features, the Second Generation was introduced. 2G is primarily voice only, but does provide higher bandwidth, better voice quality, and limited data services that use packet data technology. 2G systems are currently in wide deployment with enhanced 2G systems currently available on the market. The 3G standardization process is coming to closure, with the recent completion of the IMT-2000 radio interface recommendations.

First-Generation Mobile Standards

The first generation of cellular wireless communications was based on analog technology and progressively became available to the consumer during the late 1970’s and early 1980’s. The most successful analog systems are based on the following standards, all of which are still in demand today:

Nordic Mobile Telephone (NMT) was the first commercially available analog system, introduced in Sweden and Norway in 1979.

Advanced Mobile Phone Service (AMPS) was launched in 1982. This has proven to be the most successful analog standard of all. AMPS networks are widely deployed and can be found on all continents.

Total Access Communications System (TACS) was originally specified for the United Kingdom and is based on AMPS. The original TACS specification was extended and is known as ETACS. ETACS is primarily deployed in Asia Pacific regions.

Second-Generation Mobile Standards

The second-generation (also known as 2G) introduced digital wireless standards that concentrated on improving voice quality, coverage, and capacity. The 2G standards were defined and designed to support voice and low-rate data only—Internet browsing was in its infancy during the definition stage. The world’s four primary mobile digital wireless standards currently deployed around the world are GSM, TDMA (IS-136), CDMA (IS-95-B), and PDC, all supporting data rates up to 9.6kbps.

Global System for Mobile phone communications (GSM) was the first commercially available digital standard, introduced in 1992. GSM relies on circuit-switched data. The basic development of supporting data at low bit-rates (<9.6 kbps) was introduced at the beginning of commercial services and has been predominantly used for e-mailing from laptop computers. [2]

Time Division Multiple Access, originally IS-54 and now IS-136 (TDMA IS-136), is sometimes referred to as the "North American" digital standard; however, it is also deployed in Latin America, Asia Pacific, and Eastern Europe.

Personal Digital Communications (PDC) is the primary digital standard in Japan.

IS-95 is based on "narrowband" (referred to as narrowband because of the limited amount of information that can flow through these networks) Code Division Multiple Access (CDMA) technology. It has become popular in South Korea and North America.

Enhanced Second-Generation Mobile Standards

Enhanced second-generation (sometimes referred to as 2.5G or 2+G) builds upon the second-generation standards by providing increased bit-rates and bringing limited data capability. Data rates range from 57.6kbps to 171.2kbps.

High-Speed Circuit-Switched Data (HSCSD) provides access to four channels simultaneously, theoretically providing four times the bandwidth (57.6) of a standard circuit-switched data transmission of 14.4kbps.

D-AMPS IS-136B Time Division Multiple Access (TDMA) is the intermediate step to Universal Wireless Communication (UWC-136), a third-generation standard. The first phase of D-AMPS will provide up to 64kbps. The second phase will provide up to 115kbps in a mobile environment.

General Packet Radio System (GPRS) is an evolutionary path for GSM and IS-136 TDMA to UWC-136. It is a standard from the European Telecommunications Standards Institute (ETSI) on packet data in GSM systems. The Telecommunications Industry Association (TIA), as the packet-data SDO for TDMA-136 systems, has also accepted GPRS. GPRS supports theoretical data rates up to 171.2kbps by utilizing all eight channels simultaneously. This data rate is roughly three times faster than today's fixed telecommunication networks and about ten times as fast as current circuit-switched data services on GSM networks. GPRS is a universal packet-switched data service in GSM. It involves overlaying a packet-based air interface on the existing circuit-switched GSM network. Packet switching means that GPRS radio resources are used only when users are actually sending or receiving data. Using GPRS, the information is split into separate but related packets before being transmitted and subsequently reassembled at the receiving end. GPRS is a non-voice-added service that allows information to be sent and received across multiple mobile telephone networks. It supplements today's circuit-switched data and short messaging service. GPRS uses packet data technology, a fundamental change from circuit-switched technology, to transfer information. It also facilitates instant connection capability, sometimes referred to as "always connected." Immediacy is one of the key advantages of GPRS. Immediacy enables time-critical application services [5][6].

Third-Generation Mobile Standards

Third-generation systems will provide wide-area coverage at 384kbps and local area coverage up to 2Mbps. The primary motivation for the development of third-generation wireless communications is the ability to supplement standardized 2G and 2G+ services with wideband services. Essentially, this offers voice plus data capability.

The existing array of incompatible second-generation technologies, together with the restricted amount of information that can be transferred over these narrowband systems, prompted the ITU to work towards defining a new global standard for the next-generation broadband mobile telecommunication systems. Known as IMT-2000 (International Mobile Telecommunications-2000), the project was started to attain authorship of a set of globally harmonized standards for broadband mobile communications. The first set of IMT-2000 recommendations was recently approved by the ITU.

IMT-2000 is the term used by the International Telecommunications Union for this set of globally harmonized standards. The initiative was to define the goal of accessing the global telecommunication infrastructure through both satellite and terrestrial mobile systems. IMT-2000 has reflected the explosion of mobile usage and the need for future high-speed data communications, with wideband mobile submissions. IMT-2000 is a flexible standard that allows operators around the world the freedom of radio access methods and of core networks so that they can openly implement and evolve their systems. How they do it depends on regulations and market requirements.

The recent IMT-2000 recommendation highlights five distinct mobile/terrestrial radio interface standards:

1. IMT-MC: CDMA Multi-Carrier (known as cdma2000 or IS-2000).
2. IMT-DS: CDMA Direct Spread (known as Wideband CMDA or WCDMA-FDD). This standard is intended for applications in public macro-cell and micro-cell environments. The Frequency Division Duplex (FDD) mode is used for symmetrical applications, i.e., those requiring the same amount of radio resources in the uplink as in the downlink. This standard is well supported by Japan's ARIB and GSM network operators and vendors.
3. IMT-TC: CDMA TDD (WCDMA-TDD). Time Division Duplex (TDD) targets public micro-cell and pico-cell environments, and, due to severe interference-related considerations, is intended primarily for indoor use. This standard is optimized for symmetrical and asymmetrical applications with high data rates.
4. IMT-SC: TDMA Single Carrier (known as UWC-136 and EDGE). UWC-136 (Universal Wireless Communications) and EDGE (Enhanced Data Rates for GSM Evolution) will provide extended data services, with no changes to channel structure, frequency, or bandwidth. IMT-SC is the evolutionary path for GSM and TDMA-136, achieved by building upon enhanced versions of GSM and TDMA-136 technology. EDGE is a radio-based high-speed mobile data standard with aggregate transmission speeds of up to 384kbps when all eight timeslots are used.
5. IMT-FT: TDMA Multi-Carrier (well known as DECT, Digital Enhanced Cordless Telecommunication).

The IMT-2000 recommendations encompass three CDMA and two TDMA radio air interface standards.

Wideband Code Division Multiple Access (WCDMA) should not be confused with narrowband CDMA; they are completely different protocols. WCDMA is a younger technology, defined specifically to deliver high-speed data services and Internet-based packet-data at 3G data rates. WCDMA supports both packet and circuit-switched communications, such as Internet access and landline telephone services; however, WCDMA was defined with no requirements on second-generation backward compatibility.

WCDMA makes very efficient use of the available radio spectrum. No frequency planning is needed, since one-cell re-use is applied. Using techniques such as adaptive antenna arrays, hierarchical cell structures, and coherent demodulation, network capacity can be increased. In addition, circuit and packet-switched services can be combined on the same channel, allowing true multimedia services with multiple packet or circuit connections on a single terminal. WCDMA capacity is approximately double that of narrowband CDMA. The wider bandwidth and the use of both coherent demodulation and fast power control in the uplinks and the downlinks allow a lower receiver threshold. WCDMA uses a network protocol structure (signaling) similar to that of GSM; therefore, it will be able to use the existing GSM network as the core network infrastructure. [4]

In CDMA2000, a range of RF channel bandwidths are supported: 1.25, 3.75, 7.5, 11.25, and 15MHz. This range allows for support of a range of data rates as well as a high number of users.

In order to support higher bandwidth channels, CDMA2000 has defined two configuration options: Direct Spread (DS) and Multi-Carrier (MC). The DS option is similar to IS-95B and uses the entire bandwidth to spread the data for radio transmissions. In the MC option, user data is encoded as a single stream and de-multiplexed into multiple streams. Each stream carries part of the user data using a different carrier frequency signal, hence the name Multi-Carrier. The receiver will multiplex the received signals together before demodulation is carried out. Both the DS and MC options are available in the forward link only. The reverse link supports only the DS option. [3]

Time Division Multiple Access

One approach to reducing the number of confusing options to the end user and to improve the overall functionality of time-division cellular technology is to combine TDMA and CDMA radio air interface technology into one system. This combined approach, referred to as TD-CDMA, would retain some of the fundamental GSM-TDMA design parameters, such as frame and time-slot structure, which are key factors for interoperability and evolution. At the same time, the CDMA technology would add better interference averaging and frequency diversity. The combined approach would also merge the excellent spectral efficiency of CDMA, while retaining the robustness, planning principles, and well understood characteristics of TDMA-based GSM. [1]

In addition to the improvements of data throughput and interworking, 3G will provide an additional spectrum for the operators. The increase in 3G spectrum efficiency will also provide the operator with more throughput over limited resources. The transition from the existing 2G networks to 3G capabilities will evolve over time. Dual-mode terminals will attempt to provide seamless hand-over and roaming capabilities.

CONCLUSION

The goal of an unqualified single standard for implementation worldwide is not a reality. Operators have too much invested in their existing infrastructure and subscriber base; however, limited worldwide roaming will be possible with 3G. Even though the radio interfaces may be different, the handsets will support dual- or tri-mode operation, making the transition seamless from the subscriber's perspective.

Even with 3G radio interfaces, handsets will require dual- or even tri-mode operation, combining two or more radio standards to enable worldwide roaming. Intel is providing the building blocks to enable second- and third-generation wireless capabilities. The requirements to meet these increasing capabilities are higher performance, low-power microprocessors, highly integrated FLASH memory, and ASICs that support dual- or tri-mode standards. Intel is developing these high-performance semiconductor devices for use in RF equipment base-stations and cellular phones.

ABBREVIATIONS

The following table will help you navigate through the multiple acronyms in this paper.

2G	second-generation
3G	third-generation
3GPP	third-generation partnership project
3GPP2	third-generation partnership project 2
AMPS/ D-AMPS	advanced mobile phone system
ARIB	Association of Radio Industries and Broadcasting
EDGE	enhanced data rates for GSM and TDMA-136
ETSI	European Telecommunications Standards Institute
FDD	frequency division duplex
GPRS	general packet radio services
GSM	global system for mobile communication
HSCSD	high-speed circuit-switched data
IMT-2000	International Mobile Telecommunication-2000
ITU-R	International Telecommunication Union—Radio Communications
NMT	Nordic Mobile Telephone
PDC	personal digital communication
TACS	total access communications system
TDD	time division duplex
TDMA	time division multiple access
TIA	Telecommunications Industry Association
SDO	standards development organization
WCDMA	wideband code division multiple access
UMTS	universal mobile telecommunications system
UWC-136	universal wireless communications

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