WIRELESS CELLULAR MOBILE COMMUNICATIONS

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Abstract

In this article is briefly reviewed the history of wireless cellular mobile communications, examined the progress in current second generation (2G) cellular standards and discussed their migration to the third generation (3G). The European 2G cellular standard GSM and its evolution phases GPRS and EDGE are described somewhat in detail. The third generation standard UMTS taking up on GSM/GPRS core network and equipped with a new advanced access network on the basis of code division multiple access (CDMA) is investigated too. A sketch of the perspective of mobile communication beyond 3G concluds this article.

Keywords

Land mobile communications, cellular standard GSM, standard UMTS

1. A Brief History of Mobile Communication

With less than 50 years of commercial history, wireless mobile communications have already changed the way people communicate with each other. While progress has been impressive, much more is yet to come that will revolutionize communications as we know it, leading to communicating with anyone or any device at any place and any time.

Early two-way mobile telephone systems, from the beginning of the 20th century, used powerful transmitters to cover a distance of 30 – 50 km from a high tower or rooftop. But the reuse of any channels for a different call required in this case their separations of more than 80 – 100 km. Therefore this concept had very low spectral efficiency. As a result, most mobile radio channels were devoted for the first time to emergency and public services, until the cellular concept was invented in 1947. But world first cellular system was put into operation only in 1983, when complicated monolithic technology was matured. The cellular systems are based on the reusing the same limited radio frequency (RF) channels in a group of cells arranged in a cellular structure to serve an unlimited number of users. Furthermore, calls are automatically handed off from cell to cell.

This article describes some of the key cellular systems and technology advances that are now emerging as core for wireless communications of the future. But the cordless phone, paging, wireless local area network (WLAN) systems, and personal area systems (PAN) for mobile communication are not included in this article.

2. First Generation and Second Generation Cellular Mobile Standards

The first generation cellular wireless mobile systems (1G) before the 1990s were analog and were based on frequency division multiple access (FDMA) technology. Mobile terminals were large and weighty, placed in briefcase-sized case and mostly mounted in vehicle; that is why growth of cellular subscribers was moderate. By the end of the ′80s, however, advances in semiconductor technologies provided a vital boost to the cellular mobile industry. Using application-specific integrated circuits (ASICs), the monolithic microwave integrated circuit (MMIC) and another advanced technologies the size of the phone shrank to a small handset. Owing to the function of the phones was also changed from being able to call from a vehicle to being able to call from anywhere. This significantly increased the demand for mobile phone and boosted the penetration rate.

The second upgrading for cellular industry came from the introduction of the second generation (2G) digital technology standards. To this category belong the European *GSM* standard (*Global System for Mobile Communications*) and the two US standards *TDMA-136* (previously *IS-136*/*D-AMPS*) and *cdmaOne* (previously *IS-95*), based on time division multiple access TDMA and code division multiple access CDMA, respectively. The Japanese *PDC* (*Personal Digital Cellular*) is last significant 2G mobile standard (Fig. 1). These 2G standards have not only improved voice quality and transmission security, but also lay the foundation for the future value-added services,

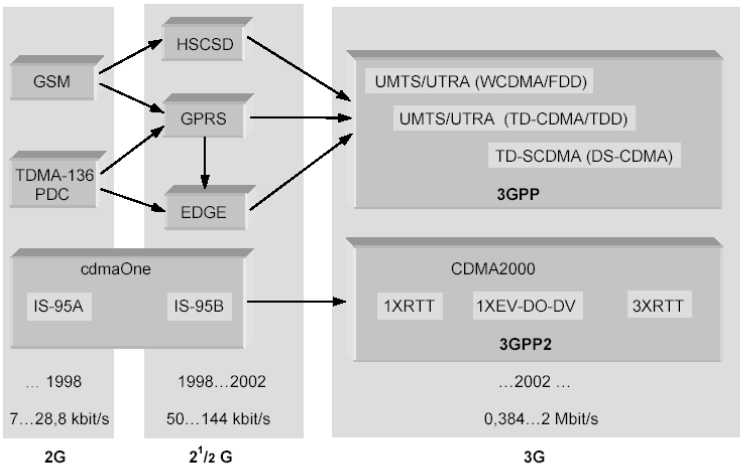

Fig. 1 Advanced cellular technology and their evolution from 2G to 3G (cordless phone, W LAN and other mobile technologies are not included in this figure)

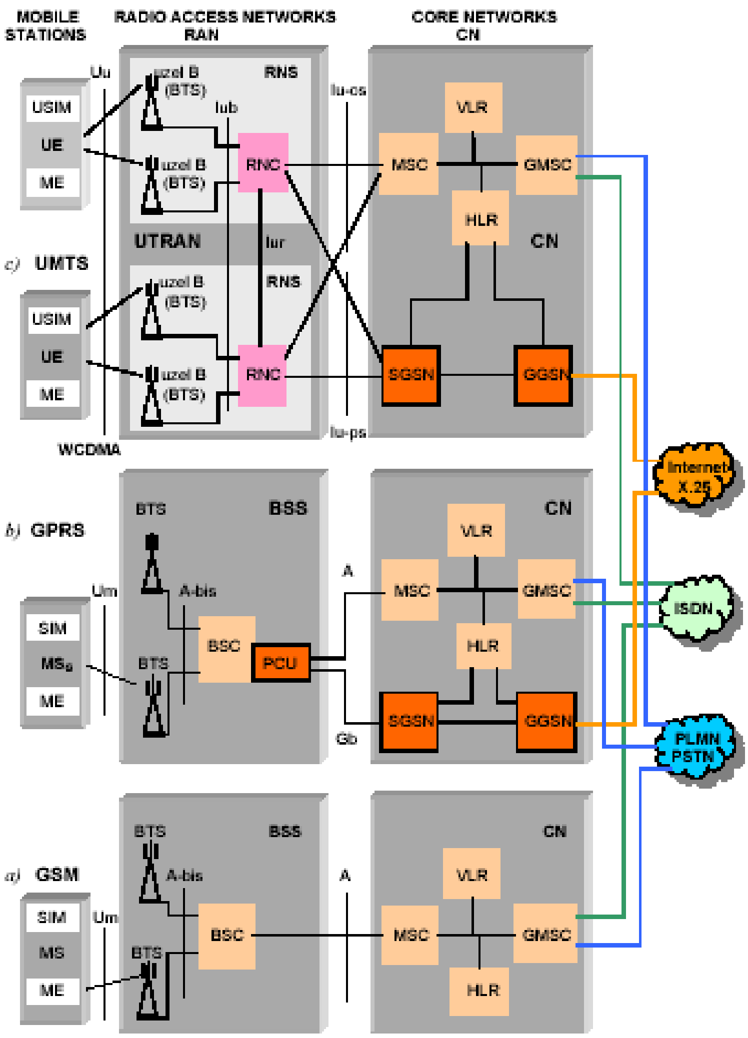

Fig. 2 Simplified cellular networks architecture: a) GSM; b) GPRS (with new nodes PCU, SGSN, and GGSN); c) UMTS (with new radio access network UTRAN)

especially for data transmission. Digital technology also radically reduces the cost of the handsets and fixed infrastructure, leading to the further acceleration of the industry growth since the mid 1990s.

The GSM simplified network configuration (phase 1) is presented in Fig. 2a. A *mobile station* (MS) communicates with a *base station system* (BSS) through *radio* (*air*) *interface* (Um). The MS consists of two parts: the smart card called *subscriber identity module* (SIM) and the *mobile equipment* (ME). In a broader definition, the MS also includes a third external part named *terminal equipment* (TE), which can be fax or PC connected to the ME. In this case, all three parts (ME, SIM and TE) are called the *mobile terminal* (MT).

The GSM radio link uses both FDMA and TDMA technology. The 900 MHz bands for the GSM downlink (DL) signal (from BSS to MS), and uplink (UL) signal (from MS to BSS) are 935-960 MHz and 890-915 MHz, respectively. The total frequency band is divided into 124 pairs of frequency duplex channel with 200 kHz spacing. The modulation method in GSM is *Gaussian Minimum Shift Keying* (GMSK). The GMSK rectangular modulation pulses are (prior to modulator) passed through a Gaussian filter with normalized bandwidth 0,3, which corresponds to an actual filter bandwidth of 81,25 kHz for an aggregate channel data rate 270,833 kbit/s per carrier. The length of a GSM/TDMA frame in a frequency channel is 4,615 ms. The frame is divided into eight time slots (bursts) of length 0,577 ms, from which is every one allocated to one user’s channel. Thus the effective radio channel transmission gross rate per user is 270,833 kbits^{-1} / 8 = 33,854 kbit/s. With GSM overhead (signaling etc), user data are actually sent at a rate 24,6 kbit/s.

Service offered by GSM (phase 1) system i.e. voice and slow circuits switched data are supported via BSS and *core network* (CN) to another user in the same GSM network, eventually in another fixed or mobile network (Public Switched Telephone Network PSTN, Integrated Service Digital Network ISDN, Public Land Mobile Network PLMN, and Internet). The BSS consists of the *base transceiver station* (BTS) that handles the radio physical layer and *base station controller* (BSC) that deals with radio resource management and handover. The CN for circuit-switched (CS) services consists of *mobile switching center* (MSC), the *visitor location register* (VLR) and *home location register* (HLR). *Gateway mobile switching centre* (GMSC) is specific MSC that acts as interface with external networks.

The GSM standard, which was being developed in the 1980s and went into commercial operation in 1991, was originally a circuit-switched system only with modest data speed of up to 9,6 kbit/s eventually 14,4 kbit/s (with more effective reduction of redundancy on the air interface) and was fully optimized for voice. Enhancement known as *high-speed circuit-switched data* (HSCSD) allows the combining of TDMA multiplexing time slots for example up to 4 at a time, with net data rate 56,7 kbit/s per one user.

As demand increased for the greater bandwidths needed in order to transmit speed data, access the Internet and generally increase the level of services, GSM made transition to the world of packet data. The first stage was *general packet radio access* (GPRS), which is based on packet transmission in the core network while using existing GSM/TDMA radio interfaces and only moderately modified RAN and CN technologies. Access RAN exploits the original GMSK modulation, but foresees four different coding schemes based on convolutional coding (rate 1/2, 2/3, 3/4, 1). These schemes afford different protection level and throughput, depending on the transmitted message type and temporary radio channel quality. The GPRS technology makes it possible to flexibly transmit data packets in unoccupied time slots in GSM channels, parallely with voice transmission. In practice, the system uses four or five of GSM´s eight time slots, permitting speeds up to about 60 kbit/s (but available theoretical maximum in this multislot mode is 115 kbit/s and finally even 172,6 kbit/s). Basically, the GPRS adds three network elements to the existing GSM infrastructure. First, the *packet control unit* (PCU) is required in BSS to manage packet segmentation, radio channel access, automatic retransmission, and power control. Second, a new entity is the *serving GPRS support node* (SGSN). The SGSN is connected with the base station controller (BSC) over a gigabit interface; it keeps the track of the location of the individual mobile stations and performs security function and access control. Third, *gateway GPRS support node* (GGSN) connects with the IP base Internet backbone. The GGSN encapsulated packets received from external packet networks (IP) and routes them toward the SGSN.

A further step in GSM evolution is e*nhanced data for GSM evolution* (EDGE). In order to increase the gross bit rate, the EDGE uses a new modulation type, 8PSK. This form offers three times higher throughput on air interface in comparison with simple GSM/GPRS using GMSK modulation; resulting maximum EDGE bit rate is 384 kbit/s. But high level, 8PSK modulation, reduces the coverage. Therefore GMSK modulation as defined in GSM/GPRS is retained in EDGE for its more robust properties in fringe areas. As in GPRS, the different initial code rates are obtained by puncturing a different number of bits from a common convolutional code. Many EDGE physical layer parameters (the carrier spacing 200 kHz, eight slots frame structure etc.) are identical to those of GSM/GPRS. Owing to EDGE can be introduced in a smooth way, using existing frequency plan of already deployed GSM/GPRS networks. At a later stage, an evolution of EDGE called GERAN will allow upgrading 2G infrastructures to offer UMTS capabilities such as real time packet services etc.

3. Third Generation Cellular Mobile Standards

At the start of the 21st century third generation (3G) systems are deployed. Recently, the global wireless industry has created two new global partnership projects 3GPP and 3GPP2, to address the issue of the limited data capabilities of 2G systems. This work resulted in 3G technologies that will provide data rates of 144 kbit/s for vehicular, 384 kbit/s for pedestrian, and 2 Mbit/s for indoor environments.

In the mobile 3G network area, the continuing trend is to move from traditional circuit-switched systems to packet-switched programmable networks, that integrate both voice and packet services, and eventually evolve towards an all-IP (Internet protocol) network. Many enabling technologies including wideband code division multiple access (W-CDMA), intelligent antennas, software defined radio (SDR), and digital signal processing devices (DSP) are greatly improving the spectral efficiency and functionality of 3G systems. The 3G mobile terminal has the potential to become a generic platform for the complete range of communication service; that is voice, data, video and multimedia.

Third generation cellular systems are on their way not, unfortunately as a single world-wide systems, but in the least as three (or even five) incompatible ones (see Fig. 1). The most important 3G standards use some forms of W-CDMA access, based on the spread spectrum techniques. The community abiding by the European GSM standard, extends itself into 3G under the general rubric of Universal Mobile Telecommunications Services UMTS (Fig. 2 c). Their radio interfaces uses W-CDMA radio techniques and is called UMTS Terrestrial Radio Access (UTRA); its hardware realization is named UTRAN (UTRA Network). W-CDMA has two forms, distinguished by how they separate the two directions of communication, that is up-link (UL), and down-link (DL). Frequency division duplexing (FDD) employs separate UL and DL frequency bands with a constant frequency offset between them. The other approach, time division duplexing (TDD), puts the UL and DL in the same band, and then time-shares transmissions in each direction. The FDD mode is convenient for outdoor applications (macrocells), the TDD mode may be useful for indoor applications (microcells) or for operators with spectrum restrictions. The W-CDMA physical layer (radio connections) includes the variable bit-rate transport channels required for bandwidth-on-demand applications. These can multiplex several services into a single connection between the fixed infrastructure and a mobile terminal.

W-CDMA applies the spreading process in two phases: an initial channellization code spreading is followed by a scrambling code spreading. The W-CDMA air interface has been designed in such a way that advanced receiver concept, e.g. a Rake receiver and multiuser detection receiver, can be deployed by the network operator consecutively.

Besides the European UTRA, one another 3G technology usually called cdma2000 (or CDMA2000) is based on W-CDMA. It can use either one carrier (1X mode) or three carriers (3X mode). The cdma2000 standard has been designed and now is deployed in the USA.

The third 3G mobile standard based on W-CDMA is *TD-SCDMA* (TDD-Synchronous CDMA), which has received the full support of the Chinese government and will surely play a critical role in mobile communication development in China as well as in the world. The TD-SCDMA technology offers several operational advantages. First, it allows the existing GSM core networks to be upgraded to the TD-SCDMA platform along a relatively easy path. Second, the use the same carrier frequency in both UL and DL (i. e. TDD duplex) helps to implement smart antenna and other technologies that rely on identical propagation characteristics in both links. Third, TD-SCDMA facilitates asymmetric traffic associated with the Internet services, where the transmission rates should be adjusted dynamically according to the specific requirements of the applications (but asymmetric traffic offers W-CDMA and cdmaOne too).

4. Evolving W-CDMA

The W-CDMA/UMTS is a flexible standard that provides simultaneous support for a wide variety of services with different characteristic on a common (single) 5 MHz carrier. By gradually introducing enhancements to the networks, operator can meet growing demands for coverage improving, capacity enhancements and flexible introduction of new services. Several of the techniques can increase of the coverage W-CDMA/UMTS system. Some of these consist of software upgrades (blind handover, fast congestion control, inter-cell load sharing, exploitation of the downlink shared channel DSCH) etc. Other will require new hardware (assigning a new carriers in existing sites, introducing adaptive antennas etc).

The enhancements described above can be applied within the current standard W-CDMA. However, to improve support for speed packed data, the 3GPP is currently working on an evolution of WCDMA known as *high-speed downlink packet data access* (HSDPA). HSDPA will increase capacity, reduce round trip delay, and increase peak data rates up to 8-10 Mbit/s. To achieve these goals, a new *high-speed downlink shared channel* (HS-DSCH) is being introduced. In addition, three fundamental technologies, which are tightly coupled and rely on the rapid adaptation of the transmission parameters to the instantaneous radio conditions, are being introduced with this channel. There are *fast-link adaptation technology*, *fast hybrid automatic-repeat-request* (ARQ) *method*, and *fast scheduling of users* sharing the HS-DSCH. The HSDPA is just one added channel, which can be used by compatible user equipment. Therefore this permits smooth introduction of HSDP.

5. Quality of Services QoS

The term quality of service (QoS) designates simply a set of service requirements to be met by the network while

Characteristics	Conversational class	Streaming class	Interactive class	Background class
Maximum bit rate [kbit/s]	< 2048	< 2048	< 2048-overhead	< 2048-overhead
Maximum packet size [bytes]	≤ 1500 or 1502	≤ 1500 or 1502	≤ 1500 or 1502	≤ 1500 or 1502
Packet error rate	10^{-2}, $7{*}10^{-3}$, $10^{-3}10^{-4}$, 10^{-5}	10^{-1}, 10^{-2}, $7{*}10^{-3}$, 10^{-3}, 10^{-4}, 10^{-5}	10^{-3}, 10^{-4}, 10^{-6}	10^{-3}, 10^{-4}, 10^{-6}
Transfer delay [ms]	100 maximum	100 maximum	traffic handling priority 1,2,3	

Tab. 1 UMTS QoS traffic classes

transporting a traffic stream from source to destination. The QoS attributes are usually specified in terms of bit error rate (BER) and/or packet error rate (PER), transfer delay and so on.

In the Quality of Services approach a set of the explicit *QoS classes* is defined. A QoS class is a composition of set of admission control rules and a set of condition traffic rules. Main services featured in UMTS can be divided into four QoS classes primarily based on their ability to tolerate PER and transfer delay. Their most important characteristics are summarized in Tab. 1. *Conversational* and *streaming* classes preserve time relation between information entities of the stream. They are suitable to carry real-time traffic since they define an upper limit on transfer delay within their QoS profiles. The most well known use of conversational class is telephony speech, but it covers also applications like voice over Internet protocol (VoIP), videoconferencing etc. Real time streaming traffic has slightly flexible delay requirements and is convenient for real time or streaming video applications for example. *Interactive* and *background* classes are mainly intended to represent conventional Internet applications (e.g. interactive Web browsing, telnet, file transfer protocol FTP, and email or file downloading), but also SMS and MMS services etc. Interactive applications have higher priority than background ones in terms of resource assignment to ensure responsiveness.

6. Future Trends in Mobile Communications

Frequency spectrum is a very scarce resource, which requires more efficient use of it and exploration of new frequency bands for wireless applications. Increasing computing power at lower cost enables new possibilities for more sophisticated signal processing algorithms for coding, decoding, detection, advanced antenna concepts, and software defined radio implementations.

These available, emerging, and evolving technologies have basically designed in the classical vertical communication model that one system has to provide a limited set of services to user in an optimized manner. In the original vision of 3G and beyond around 1990, the capabilities of different wireless access systems should be supported in all radio environments by a single radio interface. Therefore, future systems will be characterized by a horizontal communication model, where different access technologies like cellular, cordless, W LAN type systems, systems for short range connectivity and wired systems will be combined into a common platform to complement each other in an optimum way for different service requirements and radio environments. These access systems will be connected to a common, flexible, and seamless core network. Core and radio access networks will be designed for efficient packet transmission by supporting improved QoS requirements for real time services. Access networks and core networks will be implemented on Internet protocol (IP) base due to lower infrastructure costs, faster provisioning of new features, and easy integration of new network elements.

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About Author

Václav Žalud received CSc (Ph.D.) degree from the Czech Technical University (CTU) in Prague in 1969, and since 1981 he has been an associated professor there. From 1990 to 1994 he was head of the Department of Radio Electronics of the Czech Technical University in Prague. He is translator of two books, coauthor of three books, author of two books and a large number of papers.