Evolution to 3G Mobile Communication

1. Second Generation Cellular Systems

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For the last couple of years, one of the hottest topics in computing and communications has been wireless technology. During this time, the technology has attracted many users and has undergone numerous changes, including Internet connectivity. It appears that wireless technology has reached a turning point, as vendors and researchers prepare to take it to the next level. A key issue for wireless is what form the technology's next generation will take. The selection of the 'air interface' for a wireless system is a seminal decision for a service provider. The air interfaces and an overview of data transfer in cellular networks for first generation (1G) analog systems, second generation (2G) digital systems, enhanced second-generation (2.5G) systems, and third generation (3G) advanced digital cellular systems are discussed in this article. The emphasis is on covering the key characteristics of each air interface technology.

1. Introduction

The immense growth of information exchange by electronic means has caused an unprecedented boost in the development of telecommunications technologies, systems, and services. Communications that were formerly carried on wires are now supplied over radio (wireless). Thus, wireless communication, that uncouples the telephone from its wires to the local telephone exchange, has seen explosive growth. The Internet and the developments in the mobile domain have fueled the first stage of what appears to be a paradigm shift of societal dimensions. The Internet as well as corporate intranets are becoming increasingly wireless.

Keywords.
Wireless communication, cellular networks, GSM, CdmaOne, TDMA.

Cellular systems have become enormously popular. Once thought of as luxury, cell phones are now often considered a necessity and a lifeline in time of an emergency. As the cellular market becomes saturated, service providers see new data applications as the next step in providing customers with new products and services. The idea of using cells for communication can be traced back to Bell Laboratories in 1947. But it was not until 1979 that such a system was first deployed in Japan. The United States followed with a system in Chicago in early eighties. This first cellular system, which is still in use, is the American Advanced Mobile Phone System (AMPS). The Global System for Mobile Communications (GSM) widely deployed in Europe and one of the 2G standards, was believed to satisfy users' mobility demands, and probably did for a while. Today, in the world of the Internet, its limitations are revealed: it was tailored to provide a very specific service, voice communication. The current situation in mobile communications is earmarked by a tremendous growth rate, which inherently leads (and has led) to bottom-up approaches. Existing wireless networks are mostly digital and support voice communication at a low bit rate of 9.6-32 kbps. Fueled by the extensive growth of the Internet, applications are demanding that higher capacity, higher data rates, and advanced multimedia services be supported in the near future. The evolution to higher data rates and more advanced services occurs in two steps. The first step is the emergence of 2.5G systems in which the apparent deficit of GSM in dealing with voice only is exploited. 2G systems such as GSM and IS-95 are extended to provide high-speed data communications either without changing the air interface or by using improved coding techniques [1,2]. GPRS, HSCSD, EDGE, IMT2000, are the new mobile/wireless access 2.5G standards [3]. The second step is to provide higher capacity, data rates, and multimedia services which are 3G systems. Wideband code division multiple access (WCDMA) standard proposals such as CDMA2000 system include a greatly enhanced air interface to support a wider bandwidth for improved capacity and higher data rates.

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Current technology offers the nomadic user data services such as email, but higher data rates will provide far more sophisticated applications. The limiting factor to providing these new services is the transmission data rate. It has taken a decade to bring reasonable speeds to the desktop using Integrated Services Data Network (ISDN), digital subscriber link (DSL) and cable modes. To provide similar speeds to the mobile user is more difficult. Two factors are the limited bandwidth and the harsh radio frequency (RF) environment. In many ways, the cellular system is a victim of its own success. The increase in subscribers and demand for additional services requires more bandwidth, a precious and limited resource. For this reason spectral efficiency is an important cornerstone of all new technologies. By using advanced digital control systems and high-level modulation techniques, new technologies can supply high data rates in limited bandwidth.

The article is presented in two parts. Although first generation analog cellular systems slowly lose popularity and soon will have a historical meaning only, they deserve a general description, which has, been presented in Section 2. GSM, which is the most important cellular system from the European point of view, is presented in Section 3. In the same section other 2G standards CdmaOne, IS-95 and TDMA IS-136 are explained.

2. First Generation (1G) Systems

In a cellular network, there are radio ports with antennas connected to base stations (BSs) serving the user equipment, the mobile stations (MSs). The communication from the MS to the BS is the uplink, and from the BS to the MS the downlink. The downlink is contentionless, but the uplink is accessed by several MSs; therefore, another important characteristic is the multiple access technique used for its uplink. Frequency division multiple access (FDMA), Time Division Multiple Access (TDMA) [4] and Code Division Multiple Access (CDMA) [5,6] are the most widely used physical-layer multiple access techniques.

System parameters	AMPS	NMT 450	NMT 900
Transmission frequency [MHz]			
- Base station	869-894	463-467.5	935-960
- Mobile station	824-849	453-457.5	890-915
Frequency separation between Transmitter and receiver [MHz]	45	10	45
Spacing between channels [kHz]	30	25	25
Number of channels	832	180	1000
Base station coverage radius [km]	2-25	1.8-40	2-20
Modulation of audio signal	FM	FM	FM
-Frequency deviation [kHz]	±12	±5	±5
Transmitter output power [W]			
- Maximum for base station	100	50	25
- Medium for mobile station	3	1.5	1

Table 1. Basic technical parameters of AMPS and NMT cellular systems

AMPS, the first generation cellular systems using analog voice transmission came into operation in 1983 and were referred to as an analog technology. This is because the RF carrier is modulated and transmitted using frequency modulation (FM), a simple analog modulation technique, with Frequency Division Multiple Access (FDMA) as the channel multiple access method. However, the control of the connection set up, the change of the base stations during a connection, (so-called *hand*-over or *hand-off*) caused by the mobile station mobility, as well as other control procedures such as mobile station control, are implemented by transmission of digital signals.

The first mobile cellular system implemented in Europe was the *Nordic Mobile Telephone* (NMT) system. This was the first generation cellular system, which operated in a unified way in more than one country and allowed mobile communications in the whole of Scandinavia. Although outdated, while AMPS is still useful in the large territory of North American continent, NMT

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is in use in Scandinavia and some East European countries. The first generation systems suffer from poor voice quality, poor battery life, large phone size, no security, frequent call drops, limited capacity and poor handoff reliability between cells. Much more modern systems technologically better than AMPS, are now available. But no one can deny the importance of first generation system in the evolution of wireless cellular communication. It proved there was a huge demand for first generation systems, and despite its limitations, first generation systems were a huge success. However, 2G is slowly replacing them and, in the near future, 3G wireless networks.

3. Second Generation (2G) Systems

The development of the digital technology, on one hand, and frequent cases when analog systems reached their full capacity, especially in big cities, on the other hand, led to the development of the second-generation (2G) systems. The main aim in the design of the 2G systems was the maximization of the system capacity measured as the number of users per spectrum per unit area. In addition to system capacity digital 2G networks have provided improvements to system security, performance and voice quality. 2G makes heavy use of digital technology through the use of digital vocoders, Forward Error Correction (FEC), and high level digital modulation to improve voice quality, security and call reliability.

Given the popularity of cellular communication and the limited bandwidth, multiple access technology is a necessity for market expansion. 2G systems are implemented in digital technology using TDMA and CDMA that make more efficient use of the frequency spectrum, as the multiple access method. Although all methods have the same goal, they take significantly different paths in achieving it. In 1G, FDMA provided multiple accesses by separating users by RF frequency. TDMA is a narrow band technology, in which communication channels among users are apportioned by time slots. CDMA technology, developed by Qualcomm and used primarily in the US, does not divide a channel into sub-channels, like TDMA. Instead, CDMA carries multiple transmissions simultaneously by filling the entire communication channel with data packets coded for various receiving devices. The packets go only to the devices for which they are coded.

For technical reasons (e.g., frequency allocation and reuse, bandwidth) and non-technical reasons (e.g., economic, political, historical, patents) several 2G standards have evolved. The technologies fall primarily along geographic boundaries. GSM is widely deployed in Europe. CdmaOne and TDMA are widely available in North America, Korea and South America, while Personal Digital Cellular/Pacific Digital Cellular (PDC) is limited to Japan.

3.1 *Global System for Mobile Technology (GSM-2G)*

The dominant wireless-networking technology during the past few years has been 'second generation' technology, which is digital, circuit based, and narrow band but suitable for voice and limited data communications. The GSM technology has been a very stable, widely accepted and most popular standard for mobile communication. This was the first digital wireless technology and has tried to inherently support other technologies at its branches. In 2001, it enjoyed a 60% market share. In addition to voice, GSM supports low rates for data services (up to 9.6 Kbps) and Short Message Services (SMS). The GSM standard recommends the application of Gaussian Minimum Shift Keying (GMSK) modulation. This is a two-level digital FM modulation method, developed specifically for GSM and uses minimum shift keying with Gaussian filtering. The filtering smoothens rapid transitions and reduces bandwidth.

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Time-division multiple access technology, used primarily in the US, increases bandwidth by dividing each cellular channel into several time slots (a technique known as *time-division multiplexing*) each of which handles a separate transmission. The channel then switches quickly from slot to slot, thereby handling three

Basic features of GSM

Feature	GSM 900
Frequency range	
Uplink (MS→BS)	890-915 MHz
Downlink (BS→MS)	935-960 MHz
Number of duplex channels	124
Frequency intervals between uplink and downlink frequencies	45 MHz
Maximum BS power	320 W (55 dBm)
Maximum MS power	8 W (39 dBm)
Minimum MS power	0.02 W (13 dBm)
Maximum vehicle speed	250 km/h

communications simultaneously. GSM is based on time-division multiplexing but uses wider carrier frequencies. Each GSM carrier band is 200 KHz wide, and can support eight, simultaneous, full rate circuit voice users using eight time division multiple access (TDMA) bearer slots.

GMSK was developed as a compromise between conflicting goals including the need to reduce susceptibility to radio noise, reduce bandwidth and limit power to increase battery life for mobile users. These characteristics result in several highly desirable characteristics such as: increased frequency reuse (ability to support more users), lower distortion (better voice quality) and higher data rates. To support multiple accesses by users, GSM uses a combination of FDMA and TDMA.

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However, there are drawbacks to the current GSM:

- The GSM is a circuit switched, connection oriented technology, where the end systems are dedicated for the entire call session. This causes inefficiency in usage of bandwidth and resources.
- The GSM-enabled systems do not support high data rates. They are unable to handle complex data such as video.
- These devices have small hardware configurations with

less powerful CPUs, memory and display units, and support simple functionality.

- Only basic messaging services such as SMS can be supported. Also these services depend upon the service provider and the network characteristics.
- The GSM networks are not compatible with the current TCP/IP and other common networks because of differences in network hardware, software and protocols.

3.2 *CdmaOne, IS-95 (2G)*

CdmaOne, also known as IS-95 system is the branding name for the first generation of CDMA. Originally designed for voice, changes specified in IS-95A now allow packet data rates up to 14.4 Kbps. The major difference between CDMA and other 2G technologies is the modulation scheme. CDMA uses a spread spectrum technology that distributes a signal across a wide frequency (1.25 MHz) channel.

The IS-95 system operates in two bands. The Frequency Division Duplex (FDD) method is applied in both of them. The first band, Band class 0, had been previously occupied by AMPS and these frequency ranges which are now used by IS-95 are no longer used by AMPS. The downlink is realized in the frequency range 824-849 MHz and the uplink in the frequency interval 869-894 MHz and there is 45 MHz difference between both the bands. The frequency ranges for the second band (Band class 1) are 1930-1990 MHz for downlink and 1850-1910 MHz for uplink. In this standard the downlink and uplink channels are called *forward and reverse* channels, respectively.

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In transmission from a base station to mobile stations there exist four physical channels: namely, pilot channel, synchronization channel, paging channels and traffic channels. *Direct Sequence Spread Spectrum* (DS-SS) transmission at the rate 1.2288 Mchip/s is applied on all channels. The operation of all base stations is synchronized with respect to the system clock by the

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Global Positioning System (GPS). Pilot channel provides the phase and reference timing for synchronous demodulation performed by mobile stations. The synchronization channel broadcasts the data which allow for fast and reliable synchronization at the system level. The rate of the transmitted data stream is equal to 1200 bit/s. and it carries channel message and padding bits. After synchronization acquisition performed using the pilot and synchronization channels, the mobile starts to monitor the paging channel. Several messages can be sent on a paging channel. A mobile station monitors the paging channel assigned to it by the base station. Traffic channels are used to transmit user speech or data (primary traffic), data (secondary traffic) and signaling information. The user data are transmitted in the form of 20 ms frames. Due to the fact that a single traffic channel carries data at the rate equal at most to 9600 bit/s (RS1) or 14400 bit/s (RS2) the frame length is different 192 or 288 bits, respectively. Data bits in a frame can be made up of primary, secondary or signaling traffic bits separately or a composition of them. There is a long list of signaling messages and these are sent in the process of authentication, handover, power control, updating system parameters by sending information on neighbouring cells, alerting, registration, etc. The signaling message consists of an 8 bitlength header, message data of a minimum of 16 bits and a maximum of 1160 bits and a 16 bit CRC block.

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CDMA uses a sophisticated RF power control mechanism to increase capacity. Mobiles near the base station are instructed to lower power, while users far from the base station get increased power. This is commonly referred to as the 'near far' problem. Additional benefits of power control are the reduction in interference between users and lengthening of battery life.

3.3 *Major Attributes of CDMA Systems*

System capacity: The projected capacity of CDMA systems is much higher than of the existing analog/digital systems. The increased system capacity is due to improved coding gain/ modulation scheme, voice activity, three-sector sectorization, and reuse of the same spectrum in every cell and all sectors.

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Quality of service: CDMA improves the quality of service by providing robust operation in fading environments and transparent (soft) handoffs. CDMA takes advantage of multipath propagation to enhance communications and voice quality. By using RAKE receiver and other improved signal-processing techniques, each mobile station selects the three strongest multipath signals and coherently combines them to produce an enhanced signal. Thus, the multipath propagation of the radio channel is used to an advantage in CDMA. In narrow band systems, fading causes a substantial degradation of signal quality. By using soft handoff, CDMA eliminates the ping-pong effect that occurs when the mobile is close to the border between cells, and the call is rapidly switched between two cells. This effect results in handoff noise, increases the load on switching equipment, and increases the chance of a dropped call. In soft hand off, a connection is made to the target cell while maintaining the connection with the serving cell, all operating on the same carrier frequency. This procedure ensures a smooth transition between cells, one that is undetectable to the subscriber. In comparison, many analog and digital systems use a break-before make connection and require a change in mobile frequency that increases handoff noise and the chance of a dropped call.

Economics: CDMA is a cost-effective technology that requires fewer cell sites and no costly frequency reuse pattern. The

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average power transmitted by CDMA mobile stations averages 6 to 7 mW, which is significantly lower than the average power typically required by FM and TDMA phones. Transmitting less power means that average battery life will be longer.

When a mobile moves between cells, it undergoes a 'handoff.' 1G systems were plagued by interruptions during this period, commonly referred to as a hard handoff. CDMA uses a soft hand off scheme. The mobile completes the transition to the next cell before it is disconnected from the previous cell. During this transition period, the mobile communicates with both cells resulting in diversity. This diversity makes the connection more efficient and robust.

CDMA also fosters deployment of efficient wireless networks since it provides for full frequency reuse. In comparison, the adjacent cells in TDMA systems must be allocated different frequencies to insure they do not interfere with each other. Perhaps the greatest advantage of CDMA is its spectral efficiency. In real world terms, this translated to increased system capacity (users in a cell). Capacity is a key component for a service provider to consider. More capacity reduces the need for costly equipment to support additional users.

3.4 *TDMA, IS-54, IS-136 (2G)*

Time Division Multiple Access (TDMA) was originally specified as IS-54. The Telecommunications Industry Association (TIA) adopted the IS-54 standard based on TDMA to meet the growing need for increased cellular capacity in high-density areas. IS-54 retains the 30 kHz channel spacing of AMPS to facilitate evolution from analog to digital systems. Unlike CDMA that separates users by codes, TDMA separates users by time. User information is encoded transmitted and decoded in a fraction of the time required to produce it. Each user is given a small slice of airtime (timeslot). This allows all users to share the available bandwidth. TDMA uses the same frequency band and channels as 1G systems, but it provides increased capacity and improved performance. Each frequency channel provides a raw RF bit rate of 48.6 kbps. By using digital voice signals, TDMA can provide three times the capacity of standard 1G AMPS 30 KHz channel. Since IS-54 systems were to operate in the same spectrum used by the existing AMPS systems, it provides for both analog and digital operation. This is necessary to accommodate roaming subscribers, given a large embedded base of AMPS equipment. Initially the IS-54 standard used the AMPS control channel with 10 kbps Manchester-encoded frequency shift keying (FSK) [3].

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IS-136 is a frequency-shifted derivative of IS-54 for PCS bands. It includes a digital control channel (DCCH), which uses a 48.6 kbps modem. With increased signaling rate, IS-136 supports short message services (SMS), users groups, wireless private Branch exchange (PBX), and sleep modes to reduce mobile power consumption and, therefore, extend battery life. IS-54 equipment has already been deployed and is operational in a majority of the top cellular markets in the United States. IS-136 equipment has been deployed for PCS in several major cities. Two types of circuit-switched data services are provided. These include async data and Group 3 fax. The async data service supports modem-based access to PSTN subscribers. It transports user data in digital form over the radio interface, with modem residing in the PCS system. The async data service can provide access to public packet-switched networks. The upgrade path from 1G AMPS to 2G TDMA is eased by the use of dual mode cellular phones that support both. Dual mode phones allow the user continued coverage in 1G networks supported only by that technology. At the same time, the cell phone can operate in newer 2G networks where they are available.

PDC (Personal Digital Cellular/ Pacific Digital Cellular) is used primarily in Japan. It is similar to IS-54/IS-136. The major difference is the channel spacing (25 KHz vs. 30 KHz) and voice codec (VSELP 6.7 kbps vs.7.95 kbps). The modulation scheme, voice frame size, TDMA frame duration, and interleaving remain the same.

In this part of the article a general description of the first generation cellular systems, the Scandinavian NMT and American AMPS standards has been presented. The general features of GSM, the most important charcateristics of the first generation CDMA, i.e. IS-95 have also been described.

Suggested Reading

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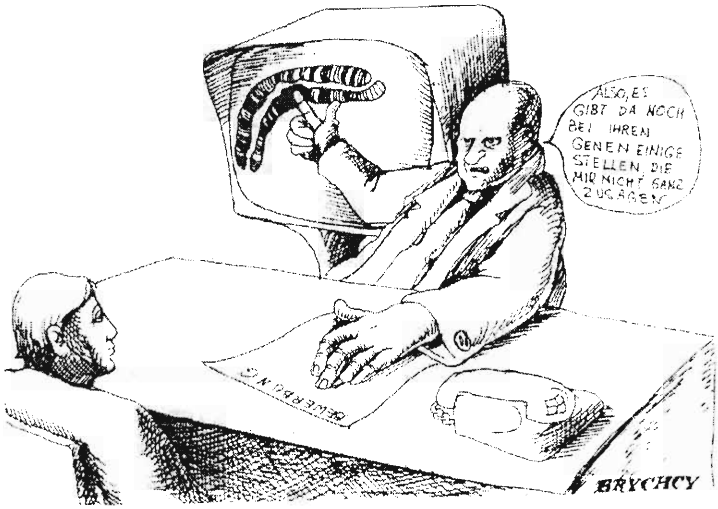

The letter reads 'Job Application'

"There are a few parts in your genes here that I'm not quite satisfied with."

From: *Gene Antics*