Evolution to 3G Mobile Communication

2. Development towards Third Generation Systems

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In the first part[1] of this article two examples of first generation cellular systems, NMT and AMPS have been described. The features of 2G, GSM, CDMA and the characteristics of first generation CDMA, IS-95 have also been discussed. In this part, the concepts of 2.5G and 3G standards are presented.

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[1] Part 1. Second Generation Cellular Systems, *Resonance*, Vol.8, No.8, pp.62-72, September 2003.

1. Evolution of 2G Systems to 3G Systems

Customer demand for digital services is the major impetus for 3G. However, there is a huge technical jump from 2G to 3G. New technologies and standards take years to develop and deploy. A gradual evolution from 2G digital telephony GSM to 3G was envisioned by telephone carriers as the logical step, and a set of extensions to GSM data services were designed and standardized, giving rise to 2.5 systems (HSCSD, GPRS, and EDGE). Researchers developed 2.5-generation technologies as upgrades to 2G approaches. 2.5G has more bandwidth than 2G but less than 3G. 2.5G uses existing 2G spectra and does not require an entirely new network infrastructure and thus can be implemented faster and less expensively than 3G. It essentially 'bridges' technologies that allow service providers a smooth transition from 2G to 3G systems. Customers also can start receiving limited 3G features before 3G is fully available. The 2.5G approach includes high-speed circuit-switched data (HSCSD) technology, a GSM extension that offers throughput of up to 38.4 kbps [1].

Keywords
Mobile networks, wireless communication, third generation systems.

2.5G systems use improved digital radio and packet-based technology with new modulation techniques to increase data rates, systems efficiency and overall performance. Their greatest advantage is that despite changes they remain compatible with 2G

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systems. An added benefit is the low cost of the changes as compared to moving to totally new 3G systems.

From a user's standpoint, the transition from 2G to 3G is transparent; 2G services are also provided by 3G services. However, from the service provider's viewpoint, the migration to 3G is difficult, risky and costly. Most 2G equipment must be replaced to support 3G. 3G also requires a larger frequency spectrum, which is particularly scarce and costly. For this reason deploying interim 2.5G systems makes sense. It provides significant improvements over 2G but does not require large investments.

1.1 *CdmaOne, IS-95B (2.5G)*

IS-95B is the packet mode version of direct sequence CDMA standard IS-95A technology. IS-95B enhancements have been introduced to allow for high-speed data packet transmission. IS-95B supports multiple codes per mobile station on both the downlink and uplink. By combining CDMA code channels, rates of 64 kbps are possible. These rates are significantly above the data rates provided by 2G systems. However they are not yet sufficient to be labeled 3G, which envisages speeds in excess of 144 kbps for mobile users and 2 Mbps for stationary users. The migration path from IS-95A, a 2G technology, to IS-95B is straightforward. Virtually all investments made by service providers remain viable. Some hardware modifications are required, but the greatest change is to the system software.

1.2. *High-Speed Circuit-Switched Data (HSCSD-2.5G) in GSM*

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Although the number of different data transmission services in the GSM is quite high, their main drawback is slow data rate. The data rate is insufficient for most Internet applications and the connections can be very expensive due to their duration. Therefore a lot of effort has been made to improve data transmission capabilities of the GSM system. Two solutions have been proposed:

- Increasing the data rate with the minimum system modification – this is realized by the assignment of several time slots to a single connection.

- Better usage of the system resources by application of packet-switched communications with the possibility of assigning several time slots in a frame for transmission of a data packet.

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As a result, substantial modifications are required.

HSCSD is a feature that enables the simultaneous allocation of multiple full-rate traffic channels (TCH/F) of GSM to a user. The aim of HSCSD is to provide a mixture of services with different air interface rates by a single physical layer structure. The available capacity of a HSCSD configuration is several times the capacity of a TCH/F, leading to a significant enhancement in the air interface data transfer capability. Ushering faster data rates into the mainstream is the new speed of 14.4 kbps per time slot and HSCSD protocols that approach wire line access rates of up to 57.6 kbps by using multiple 14.4 kbps time slots. The increase from the current baseline 9.6 kbps to 14.4 kbps is due to a nominal reduction in the error-correction overhead of the GSM radio link protocol (RLP), allowing the use of a higher data rate.

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For end users, HSCSD enables the roll-out of mainstream high-end segment services that enable faster Web browsing, file downloads, mobile video conference and navigation, telematics, and bandwidth-secure mobile LAN access. Value added service providers (VASP) will also be able to offer guaranteed quality of service and cost efficient mass-market applications, such as direct IP where users make circuit-switched data calls straight into a GSM network router connected to the Internet. To the end user, the VASP or the operator is equivalent to an Internet service provider (ISP) that offers a fast, secure dial-up service at cheaper mobile-to-mobile rates. HSCSD was the first major attempt to improve data transmission capabilities of the GSM system. Due to the assumption about introducing few changes in the system, the HSCSD remains a circuit-switched system, as the standard GSM is. Therefore it is not well suited to the packet traffic which is characteristic for data transmission. The reservation of more than one time slot during the whole data exchange session increases the probability of blocking in a cell.

One disadvantage is reduced network voice capacity, since it removes channels from service that would normally be used to support voice calls. Since the user requires more system resources, the cost of the connection can be significantly higher than a normal voice call. Nevertheless, this enhancement does allow GSM systems to support higher data rates. HSCSD lessens the financial impact of providing users with higher data rates since it is primarily a software upgrade. Some hardware is required in the form of gateway equipment to connect the system to data networks (e.g., the Internet). But this equipment is minimal and easy to implement.

1.3. *General Packet Radio Service (GPRS – 2.5G)*

The next phase in the high speed road map is the evolution of current short message services, such as smart messaging and unstructured supplementary service data (USSD), toward the new GPRS, a packet data service using TCP/IP and X.25 to offer speeds up to 171 kbps [2]. This data rate is high enough to permit video conferencing and interacting with multimedia Web sites. GPRS is a major improvement and extension of the standard GSM system, which takes into account the increasing demand for data transmission over mobile networks. Data transmission rates in the existing mobile networks were insufficient and the connection set-up time was long. The circuit-switched transmission was not well fitted to the bursty and asymmetric nature of data traffic; therefore the existing system resources were used inefficiently. As a result, it was decided that packet-switched transmission should be applied. Thus, system users can share the same physical channels and the system resources can be used much more efficiently due to statistical multiplexing.

GPRS is a major improvement and extension of the standard GSM system, which takes into account the increasing demand for data transmission over mobile networks.

GPRS has been standardized to optimally support a wide range of applications ranging from very frequent transmission of medium and large data volume to infrequent transmission of large data volume. GPRS has been developed to reduce connection setup time and allow an optimum usage of radio resources. It provides a packet data service for GSM where time slots on the air interface are multiplexed to transmit packet data from several mobile stations. The consequence of packet switching is a tariff system based on the number of transmitted packets. The session can last for a long time but the user pays for the transmitted data volume only. GPRS differs from HSCSD by achieving improved transfer speeds by dynamically assigning time slots on GSM radio channels [1].

GPRS provides a core network platform for current GSM operators not only to expand the wireless data market in preparation for the introduction of 3G services, but also a platform on which to build IMT-2000 frequencies should they acquire them. GPRS enhances GSM data services significantly by providing end-to-end packet-switched data connections. This is particularly efficient in Internet/intranet traffic, where short bursts of intense data communications activity are interspersed with relatively long periods of inactivity. Because there is no real end-to-end connection to be established, setting up a GPRS call is almost instantaneous and users can be continuously online. Because GPRS does not require any dedicated end-to-end connection, it only uses network resources and bandwidth when data is actually being transmitted. This means that a given amount of radio bandwidth can be shared efficiently and simultaneously among many users. Thus GPRS goals are to efficiently service data sources and to provide a packet switched service that shares GSM resources. The physical layer (air interface) of GPRS is the same as GSM. The challenge is maintaining compatibility with the circuit-switched GSM network and the packet-switched Internet system. GPRS uses the same GSM modulation scheme, frames and multiple-access method. The implementation GPRS has a limited impact on the GSM core network. It simply requires the

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addition of new packet data switching and gateway nodes, and an upgrade to existing nodes to provide a routing path for packet data between the wireless terminal and a gateway node. The gateway node provides interworking with external packet data networks for access to Internet, intranets, and databases.

GPRS will support all widely used data communications protocols, including IP, so it will be possible to connect with any data source from anywhere in the world using a GPRS mobile terminal. GPRS will support applications ranging from low speed short messages to high-speed corporate LAN communications. However, one of the key benefits of GPRS – that it is connected through the existing GSM air interface modulation scheme – is also a limitation, restricting its potential for delivering data rates higher than 115 kbps. To build even higher rate data capabilities into GSM, a new modulation scheme is needed.

1.4 *Enhanced Data Rates for GSM Evolution (EDGE 2.5G)*

EDGE, developed initially by Ericsson and scheduled for commercial use this year, provides an evolutionary path that enables existing 2G systems (GSM, IS-136) to deliver 3G services in existing spectrum bands. Like GSM, it supports voice, but provides significant data rate improvements. EDGE reuses the GSM carrier bandwidth and time slot structure. The standardization effort for EDGE has two phases. In the first phase the emphasis has been placed on enhanced GPRS (EGPRS) and enhanced CSD (ECSD). The second phase is being defined with improvements for multimedia and real-time services as possible work items.

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The EDGE air interface is designed to facilitate higher bit rates than those currently achievable in existing 2G systems. The modulation scheme based on eight level phase shift keying (8-PSK) is used to increase the gross bit rate. Using enhanced 8-PSK modulation a three-fold data rate increase over standard two-level GMSK modulation is possible. Specifically, EDGE provides 69.2 kbps/slot throughput vs. 22.8 kbps/slot of a standard GSM carrier. Throughputs can be further increased to approximately 474 kbps by using multiple slots.

The improved data rates are not free. In the case of EDGE, 8-PSK provides higher data rates at the cost of requiring higher signal to noise ratios. This typically means higher RF power requirements. A mobile terminal can save power by supporting 8PSK only when RF signal conditions are favorable. Another consequence of 8 PSK modulation is the need for increased linearity of costly RF power amplifiers.

EDGE's major advantage is that by modifying the GSM air interface slightly, EDGE modulation can be time inserted on a slot-by-slot basis. This allows EDGE systems to coexit with GSM systems. First generation GSM cellular phones will ignore EDGE time slots since they cannot be demodulated or decoded. The evolutionary path from GSM to EDGE has minimal impact on the existing network architecture and the ability to reuse installed equipment is a big advantage. Changes to support EDGE are limited to the radio portion of the network (e.g., base station); all other network interfaces remain largely unchanged.

2. Third Generation (3G) Systems

Since existing systems operate in selected environments only, it would be desirable to create a new universal system (3G system), which could operate anywhere, anytime using unified equipment. Also, taking into account the limitations imposed by the finite amount of radio spectrum available, the focus of 3G mobile systems is an economy of network and radio transmission design to provide seamless service from the customer perspective. Third-generation systems are perceived as the wireless extension of future fixed networks, as well as an integrated part of the fixed network infrastructure [3].

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The research on third generation systems was initiated long before the potential of the GSM and other second-generation systems were exhausted. The aim was to create a global standard, which would enable global roaming. The International Tele-

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communications Union (ITU) began to work on the third generation mobile communication system by defining the basic requirements. The system was initially called Future Public Land Mobile Telecommunication System (FPLMTS) and now is known as International mobile Telecommunications (IMT-2000). Minimum IMT-2000 requirements include:

High-speed data transmissions: 3G will bring an order of magnitude improvement to data communications enabling bandwidth hungry multimedia applications. Although the use of email and web browsing is skyrocketing, they are not killer applications that justify a high investment in 3G. Multimedia and video conferencing are the services that are expected to justify the new infrastucture. 3G data rates fall into three categories:

- 2 Mbps for indoors and for pedestrians.
- 384 kbps for terminals moving at no more than 120 km/h in urban areas.
- 144 kbps in rural areas and for fast moving vehicles.

Symmetrical and asymmetrical data transmission support: Email and web browsing is predominately asymmetrical. For example, data transmitted to the user is much greater than that transmitted by the user. However, services such as video conferencing are symmetrical resulting in equal data transmission in both directions.

Improved voice quality: Provide voice quality comparable to that of wire-line telephony.

3G is expected to support international roaming. Currently, roaming between international networks requires a different cellular phone for each network.

Greater capacity: With the explosion in usage, the need to efficiently use the frequency spectrum is imperative.

Multiple simultaneous services: This allows, for example, a user to download an MP3 audio file while talking on the same cellphone.

Support of global mobility: 3G is expected to support international roaming. Currently, roaming between international networks requires a different cellular phone for each network.

Improved security: Users will be able to communicate and conduct business in a secure environment. This will ultimately foster additional commercial services.

Service flexibility: Both circuit-switched (e.g., voice, real-time video) and packet-switched services (e.g., Internet Protocol) shall be supported.

Third generation (3G) wireless systems will offer access to services anywhere from a single terminal; the old boundaries between telephony, information, and entertainment services will disappear. Mobility will be built into many of the services currently considered as fixed, especially in such areas as high-speed access to the Internet, entertainment, information, and electronic commerce (e-commerce) services. The distinction between the range of services offered via wireline or wireless will become less and less clear and, as the evolution toward 3G mobile services speeds up, these distinctions will disappear within a decade.

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Applications for 3G wireless networks will range from simple voice-only communications to simultaneous video, data, voice and other multimedia applications. One of the main benefits of 3G is that it will allow a broad range of wireless services to be provided efficiently to many users.

Packet-based Internet Protocol (IP) technology will be at the core of the 3G services. Users will have continuous access to online information. Email messages will arrive at hand-held terminals nearly instantaneously and business users will be able to stay permanently connected to company intranets. Wireless users will be able to make video conference calls to the office and surf the Internet simultaneously, or play computer games interactively with friends in other locations.

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The 3G specifications required participation from companies and agencies worldwide to assure that the standard is globally accepted. In 1998, the 3GPP (third generation partnership project) was established in order to define a common wideband

CDMA standard. As a result the Universal Mobile Telecommunications System (UMTS) was defined. However, those partners who wished to extend the IS-95 system also promoted an alternative standard called CDMA2000. The 3GPP developed the UMTS Frequency Division Duplex (FDD) and UMTS Time Division Duplex (TDD) specifications with 5 MHz carrier spacing. The 3GPP2 produced 1xEVDO (IS-856) that is a part of the larger CDMA2000 specification. Other technologies such as Digital Enhanced Cordless Telecommunication (DECT+) also come under the 3G umbrella. They also agreed upon the standards MC CDMA (Multicarrier CDMA) and UWC136 (Universal Wireless Communications). UWC136 standard is based on the convergence of IS136 and GSM EDGE. The UWC136 will be a natural extension of TDMA systems. However, they are not expected to be widely deployed due, in part, to the technical superiority of other technologies, as well as non-technical business and political issues. In fact three different IMT-2000 standards were agreed upon:

- UTRA (UMTS Terrestrial Radio Access) – wideband CDMA transmission with FDD and TDD modes and 5 MHz carrier spacing,
- MC CDMA (Multicarrier CDMA),
- UWC136 (Universal Wireless Communications) – based on the convergence of IS-136 and GSM EDGE. The UWC136 will be a natural extension of TDMA systems.

2.1 *UMTS (3G)*

The basic purpose of introducing UMTS is to support integrated digital wireless communications at data rates up to 2Mbps in the 2 GHz band. *Table* 1 presents the bands allocated to the UMTS.

The UMTS requirements are similar to those stated for IMT-2000 [4]. They are:

Operation in various types of environment: The terrestrial part

Frequency [MHz]	Bandwidth [MHz]	Destination
1900-1920	20	UMTS (terrestrial), TDD
1920-1980	60	UMTS (terrestrial) FDD, UL
1980-2010	30	UMTS (satellite) FDD, UL
2010-2025	15	UMTS (terrestrial) TDD
2045-2110		
2110-2170	60	UMTS (terrestrial) FDD, DL
2170-2200	30	UMTS (satellite) FDD, DL

Table 1. UMTS spectrum allocation.

of the UMTS will operate in several environments, from rural to indoor. There will be three basic types of cells fitted to these environments: picocells, microcells and macrocells with appropriate physical layers of the UMTS.

The choice of duplex transmission: The bandwidth allocated consists of two paired bands and two unpaired bands. Frequency division duplex transmission is applied in the paired bands and time division multiplex in unpaired bands.

A wide service offer: The UMTS should support a large selection of services, from voice transmission to fast data transmission. The traffic can be asymmetric. The system should be flexible enough to allow for the introduction of new services in the future.

Integration with fixed networks: The UMTS will be integrated with wireline wideband networks such as B-ISDN.

Following the above requirements a list of services has been proposed and their quality has been defined. *Table* 2 gives the service proposals. The UMTS offers voice, data and video telephony transmission. Besides that, it can be treated as a wireless extension of integrated services digital networks. Therefore the system supports basic ISDN access at the rate of 144 kbps (two B channels plus a D channel). Data transmission at the rate of 2 Mbps, possible in a limited range, allows transmission of compressed video. Similar to the second-generation systems, the UMTS will ensure a high level of security of transmitted data. It

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Type of Service	Data Rate	Error Rate	Allowable Delay
		[kbps]	[ms]
Speech transmission	4.75-12.2	10^{-4}	40
Voice band data	2.4-64	10^{-5}	200
Hi-Fi sound	940	10^{-6}	200
Videotelephony	64-144	10^{-7}	40-90
Email	0-384	10^{-6}	many minutes
Facsimile (G4)	64	10^{-6}	100
Broadcast or multicast Transmission	1.2-9.6	10^{-6}	100
Short messages/paging	1.2-9.6	10^{-6}	100
Web browsing	16-64 (UL)	10^{-6}	seconds
	96-384 (DL)	10^{-6}	
Access to database	2.4-768	10^{-6}	200
Teleshopping	2.4-768	10^{-7}	90
Electronic newspaper	2.4-2000	10^{-6}	200
Navigation and location	64	10^{-6}	100

Table 2. Examples of services in UMTS.

is important not only for the privacy of individual telephone calls, but also for the support of tele-banking and e-commerce.

UMTS applies a high quality Adaptive Multi-Rate (AMR) speech coding based on Algebraic Code Exited Linear Prediction (ACELP) coding with discontinuous transmission and comfort noise insertion. It works at 8 different bit rates: 4.75, 5.15, 5.90, 6.70, 7.40, 7.95, 10.20, and 12.20 kbps. Three of them are compatible with speech coders applied in the existing second-generation systems: 4.70 kbps PDC EFR, 7.40 kbps IS-641 (US TDMA/IS-136) and 12.20 kbps GSM EFR. The data rate of the AMR coder depends on the network load, the service level specified by the network operator and the current SNR value.

UMTS is also referred to as Wide band CDMA (WCDMA). WCDMA is now recognized as one of the leading candidates for third generation wireless access. It gets its name from its 5 MHz wide bandwidth requirement and is based on direct-sequence spread-spectrum with a chip rate of 3.84 Mcps. It will support

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circuit and packet data access at nominal rates up to 384 kbps in macrocellular environments, and provide simultaneous voice and data services. The large bandwidth of WCDMA stems from the direct sequence chip rate of 3.84 Mcps. This is much larger than the 1.2288 Mcps rate of CdmaOne and CDMA2000 1xRTT (1time Is-95 Radio Telephone Technology) that requires 1.25MHz, and the 3.6864 Mcps rate of CDMA2000 3x multicarrier (3x MC). The chip rate is the primary difference between the two technologies and a major reason for their incompatibility [3,4].

The transition from GSM to WCDMA requires a new frequency spectrum because of the 5 MHz of bandwidth that the WCDMA waveform requires. It cannot fit into the smaller spectrum space currently allocated to GSM. This and other factors make the transition from GSM to WCDMA revolutionary. Besides the frequency spectrum required, the modulation method is very different. This makes the technologies incompatible and more accurately labels WCDMA as a new design rather than an evolution or enhancement of GSM.

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2.2. *CDMA2000, IS-2000 (3G)*

CDMA2000 is one of the most important proposals for an IMT-2000 air interface. CDMA2000 is formally documented as IS-2000 and builds on its predecessor CdmaOne (IS-95). It has much in common with the 2G version of CDMA. It uses similar modulation techniques and Walsh codes but enhancements give it greater flexibility and performance. One major improvement of CDMA2000 is its ability to support higher data rates. Peak data rates of 153 kbps are possible with low-end phones, and rates as high as 307 kbps are possible with high-end phones and devices. Additional changes to the IS-95 specification nearly doubles voice capacity and the addition of a 5ms frame supports 'quick paging' which improves battery life. CdmaOne offered some security predominantly by the sheer complexity of its design. However, CDMA2000 offers complex scrambling to support privacy. The first phase of CDMA2000 called CDMA2000

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1x is an extension of the existing IS95B standard. It allows doubling of the system capacity and increased data rates up to 614 kbps. The second phase called CDMA2000 1xEV (Evolution) is a further enhancement of CDMA2000 1x. It includes High Data Rate (HDR) technology providing data rates up to 2.4 Mbps [3].

IS-2000 also supports smart antenna technology that significantly improves system capacity. Smart antennas can be steered electronically. This allows RF energy over a wide area that dilutes the signal, causes interference and, ultimately, lowers capacity. The path from CdmaOne to CDMA2000 will have minimal impact predominately due to the similarities of the two technologies.

Initially, a dedicated carrier is devoted to high-speed packet data, whereas one or more additional carriers are used to realize voice connections. In later developments of the 1xEV, packet data and voice transmission will be combined in the carrier; however, packet services on a separate carrier may be possible. Finally, in the third phase of CDMA2000 development, called CDMA2000 3x, three independent non-overlapping CDMA channels are used, retaining backward compatibility with CDMA2000 1x and IS-95B. Tripling the bandwidth and giving some additional freedom results in service enhancement and data rates up to 2 Mbps.

The CDMA2000 is designed to operate in the following environments:

Outdoor mega cells (cell radius >35 km),
Outdoor macrocells (cell radius 1 – 35 km),
Indoor / outdoor microcells (cell radius < 1 km),
Indoor / outdoor picocells (cell radius < 50 m),
Wireless local loops.

2.3. *CDMA 2000 1xEV-DO, IS-856 (3G)*

1xEV-DO [5] is a data service technology that is formally specified as IS-856. EV signifies that it is an evolutionary technology built on the IS-95 standard.

What differentiates it from other 3G technologies is that it supports Data Only (DO). Voice services are not provided. By optimizing the system for packet data, it is not limited by voice timing requirements that are significantly different from data requirements. 1xEV-DO provides an always-on connection, which provides seamless Internet connectivity.

IS-856 can provide peak data rates of 2.4 Mbps in a 1.25 MHz IS-95 CDMA channel. It is also spectrally efficient. Given the cost associated with a large frequency spectrum, the importance of this characteristic cannot be overstated. Simulations with fixed and mobile users show that a spectral efficiency of 1bit/sec/Hz is achievable. The high spectral efficiency is accomplished by a combination of adaptive coding rate and adaptive modulation technique.

3. Conclusion

Analog 1G wireless cellular systems had many weaknesses, but their importance cannot be overstated. They showed there was a huge worldwide market for mobile communication. Digital 2G technology solved many of the weaknesses of 1G, added services, and saw the beginning of low speed data communication. Present cellular systems are based on TDMA and CDMA technologies, and provide packet data transmission at low rates. Advanced digital 3G technology represents a quantum leap in technology from 2G. 3G mobile telecommunications systems pave the way for future access to advanced multimedia services like mobile Internet or videoconferencing.

Suggested Reading

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