4 ยุคของระบบการสื่อสารไร้สายแบบเซลล์ลูลาร์

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บทคัดย่อ

บทความนี้เสนอประวัติความเป็นมาของระบบการสื่อสารเคลื่อนที่ไร้สายแบบเซลล์ลูลาร์ในยุคที่ 1, 2, 2.5, 3 และเส้นทางสู่ยุคที่ 4 ซึ่งจะเป็นการสื่อสารแนวมัลติมีเดียเคลื่อนที่ (mobile multimedia) บทความเริ่มต้นด้วยประวัติศาสตร์ในการวิวัฒนาการระบบการสื่อสารเคลื่อนที่ไร้สายที่ไม่เป็นแบบเซลล์ลูลาร์ ต่อมามาตรฐานการสื่อสารเคลื่อนที่ไร้สายแบบเซลล์ลูลาร์ยุคแรกก็เกิดขึ้นในประเทศแถบทวีปยุโรป, ประเทศสหรัฐอเมริกา และประเทศญี่ปุ่น ระบบเซลล์ลูลาร์ยุคที่หนึ่งเป็นแบบแอนะลอกที่ใช้สำหรับการสื่อสารของสัญญาณเสียงเท่านั้น เพื่อที่จะตอบสนองต่อความต้องการที่มากขึ้นภายใต้ขีดจำกัดของทรัพยากรความถี่จึงผลักดันให้เกิดยุคที่ 2 ซึ่งเป็นแบบดิจิตอล ระบบในยุคที่ 2 มี 2 แบบ ซึ่งแบ่งตามการตอบสนองจำนวนผู้ใช้ที่แชร์ย่านความถี่ในเวลาเดียวกัน (multiple access) โดยใช้เทคนิคทางเวลาและทางรหัส (TDMA และ CDMA) ปรากฏว่า GSM ซึ่งใช้แบบทางเวลาได้รับความนิยมทั่วโลกและสามารถ โรมมิ่ง (roaming) ข้ามประเทศได้ มาตรฐานยุคที่ 2.5 พัฒนาให้มีอัตราการส่งข้อมูลสูงขึ้นและเป็นการส่งแบบแพ็กเกต (packet) เพื่อสนับสนุนการส่งทั้งเสียงและข้อมูลความต้องการรวมของหลายๆ มาตรฐานที่เกิดขึ้นในยุคที่ 2 ให้เป็น มาตรฐานเดียวกัน, ความสามารถโรมมิ่งทั่วโลก, การบริการส่งข้อมูลแบบมัลติมีเดียด้วยความเร็วถึง 2 เมกะบิตต่อวินาทีในแถบความถี่กว้าง, และมีคุณภาพเหมือนกับการสื่อสารแบบมีสาย ทั้งหมดคือเป้าหมายหลักของการสื่อสารยุคที่ใช้กันปัจจุบันนี้หรือยุคที่ 3 ซึ่งมีชื่อมาตรฐานว่า IMT-2000 เนื่องจากมีการใช้อินเตอร์เน็ตกันอย่างแพร่หลาย แนวโน้มของยุคต่อไปน่าจะเป็นแบบอินเตอร์เน็ตเคลื่อนที่ ระบบของยุคที่ 4 จะสามารถติดต่อข้ามโครงข่ายต่างมาตรฐาน ได้โดยใช้ Internet Protocol (IP) เป็นตัวเชื่อมกับอุปกรณ์ปลายทางที่ฉลาดภายใต้การควบคุมของซอฟต์แวร์ที่ปรับรูปลักษณ์ได้ (reconfigurable software radio) การบีบอัดข้อมูลที่มีประสิทธิภาพขึ้นประกอบกับใช้แถบความถี่กว้างทำให้ความเร็วในการรับส่งข้อมูลของยุคที่ 4 สูงกว่าของยุคที่ 3 ส่วนท้ายของบทความจะเป็นแนวคิดหลักที่น่าจะเกิดขึ้นในยุคที่ 4

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4 Generations of Cellular Wireless Systems

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Received 14 October 2002; accepted 18 March 2003

Abstract

In this article, the standards of the first, second, second and half, third generation mobile cellular radio systems and a path toward the fourth generation mobile multimedia communication are reviewed. Non-cellular mobile wireless evolution is historically given. First generation wireless standards designed in the European countries, US and Japan were voice-only analog cellular systems. Explosive growth of the demands in limited spectrum resulted in the second generation that was all based on digital. The second generation systems are categorized by the multiple access techniques: TDMA and CDMA. It turned out that TDMA-based GSM has become the dominant mobile system all over the world yielding to international roaming. Further development of half generation to 2.5G was evolved to speed data rates and packet data transmission to integrate voice and data applications. Seamless integration of the existing second generation wireless networks, global roaming, broadband data services and mobile multimedia up to 2 Mbps data rate with the same quality as that of wireline are all the main goals of the third generation standards, called IMT-2000, which have now been deployed. Motivated by the rapid growth of Internet, mobile Internet will be an extension of the third generation services. The fourth generation systems will be able to interwork over heterogeneous networks based on a common IP-platform and smart terminals controlled by reconfigurable software radio. It is also expectedly to support higher data rate than the third generation possible by data compression techniques in broadband radio transmission. Some perspectives of the coming fourth generation are concluded.

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1. Introduction

Wireless communication services have witnessed explosive growth along the globalization era. Cellular phones become one of the most dynamic facilities to communicate with people on the move, as a testimony of "wireless catching up with wireline". The growth of worldwide cellular and personal communication subscribers will be reached to 2 billions expected by the end of 2005 [1]. Cellular subscription increases of 40% or more per year have experienced in most countries [2]. These astoundingly demands have driven generations of cellular networks to meet the need of anywhere, anytime and by means of any portable units in miniature size as well as consuming a minimum of power for multimedia transmissions at effective-cost.

However, wireless technology is not just recent. That was begun in 1897 with the success of Guglielmo Marconi's invention, mobile-radio telegraphy contacting with ships sailing the English channel over an 18-mile path [3]. It was the first milestone in shared use of the radio spectrum. His well-known vision was given "it is dangerous to put limits on wireless" (1932). Historically, mobile wireless communication field had evolved slowly due to gradually technological improvement before World War II. Later, progressive technology advances permitted the communication world to be more mobile in more coverage. Throughout the 19^{th} century and the beginning of new millennium, great advances in wireless system were made on both terrestrial and satellite mobile-radio communication incooperating the cellular technique.

2. Predecessors to Cellular

Let's take off with some historical highlights. By 1934, Amplitude Modulation (AM) mobile system was initialized for public safety by 194 municipal police radio stations and 58 state police stations in the US. Then, it was surely replaced with Frequency Modulation (FM). In 1946, the first mobile telephone service for publicity was implemented by AT&T in 25 main American cities and named the Mobile Telephone Service (MTS) standard [4]. There were many shortcomings, although, the MTS was successful. The configuration of such system is similar to a broadcast model i.e. having a single cell and high power transmitter to have large coverage (prone to interferences). It uses FM at a carrier frequency of 150 MHz with 120 kHz bandwidth (too broad) in a half duplex mode. Additionally, it was a non-trunk system then a call could be blocked if the specific channels were not available. Also, no handoff was supported then calls could be dropped when a subscriber was crossing at the boundary of cells.

With technological improvement from World War II to the mid 1960s, the number of duplex channels per market could be double without new spectrum allocation by decreasing the required channel bandwidth from 120 kHz to 60 kHz in 1950 and from 60 kHz to 30 kHz in 1965. In addition to four times increased spectrum efficiency, automatic trunking was introduced and implemented in 1965 and then a call could be placed in any open channels. As such, probability of call blocking was lower. That is the number of subscribers was more supported simultaneously. This improved standard was so-called Improved Mobile Telephone Service (IMTS) [5]. Although, IMTS offered full-duplex, auto-dialing and auto-trunking systems, significant improvement over MTS, it has no handoff feature. Moreover, IMTS system still could not support customers in great demand such as that of New Yorkers [6].

3. Cellular Concept

The cellular concept was conceived during 1960s by the US at AT&T Bell Labs [7-8]. Due to spectrum limit and growing demands, cellular technique offers an efficient spectral usage. It utilizes the fact that signal strength decays as the distance of separation between a transmitter and receiver increases. Consequently, frequencies can be reused without interfering if the transmitters using the same set of radio channels are a sufficient distance apart.

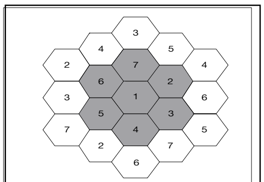

Figure 1 : Celullar Frequency Reuse

A region is broken into a small area called a cell as pictorially shown in Fig. 1. Hexagonal-shaped cells is to cover the entire service area with no gaps and overlaps. Each cell is allocated a portion of total available channels for connecting base station (BS) and mobile stations (MS). The cluster of seven shaded cells shares all available spectra. As transmitted power strength decays with distance, cells far apart can be assigned the same set of frequencies and called co-channel cells (marked by the same numbers in Fig. 1).

This cell-related frequency allocation has been remarkably successful. However, there is a trade-off in actual cellular design between co-channel interference and capacity of frequency reuse. In theory, having more cells per cluster provides more interference immunity but less capacity [2]. By means of cell-splitting or sectoring, one can improve the capacity but pay for an increased number of base stations for cell-splitting or number of directional antennas for sectoring. Both ways increase handoff rates which turn to complicate designs.

4. The First Generation (1G)

Cellular concept was a reality due to the two inventions, microprocessors and the use of digital control link between BS and MS. 1G cellular systems began to be deployed throughout the world since the early 1980s [9]. All are based on FM for audio signal and frequency shift keying for control signal modulations. It was first operated in 1979 by the Nippon Telephone and Telegraph (NTT) company in Japan. The system used 600 FM duplex channels with 25 kHz bandwidth in the 800 MHz band.

There were many standards occurring in Europe. First, the Nordic Mobile Telephone system (NMT-450), developed by Ericsson in 1981 and belonged to Scandinavian. It operated in 450 MHz band offering 180 FM duplex channels of 25 kHz bandwidth. Subsequently, the United Kingdom introduced Total Access Communications System (TACS) in 1982 and developed to the Extended Total Access Cellular System (ETACS) in 1985. Unlike NMT-450, it operated in the 900 MHz band whose number of channels was 1000 with 25 kHz bandwidth each. In 1985, the 450 MHz band was also used in Germany for the cellular system named C-450. The number of C-450 channels was 222 that was greater than NMT-450's due to narrower bandwidth (20 kHz). Radicom 2000 of France was introduced in 1985.

In the US, there was only an analog cellular standard called Advanced Mobile Phone System (AMPS) [10], developed by AT&T and Motorola. It was the first operation in Chicago by Ameritech in 1983. AMPS allocated 800 MHz band into 666 channels having a bandwidth of 30 kHz. According to the duopoly of the FCC (Federal Communications Commission) rule, two cellular radio companies (wireline and nonwireline carriers) served markets thus to control levels of pricing. In 1989, the FCC allocated additional 166 channels or 10 MHz resulting in an increased number of channels to 832.

Table 1 summarizes the popular 1G cellular telephone standards. Most of the standards performed wideband FM which have no much capacity to accommodate new subscribers. As a consequence, narrowband FM analog systems replaced them into Narrowband AMPS (NAMPS) and narrowband TACS (NTACS) [11]. Their multiple accesses and duplexing are frequency division multiple access and frequency division duplexing (FDMA/FDD).

Table 1 A comparison of operational aspects for the first generation cellular systems

Standards (year introduced)	Country	Number of duplex channels	Frequency band Tx:BS;Tx:MS*(MHz)	Channel bandwidth (MHz)
AMPS (1983)	US	832	869-894; 824-849	30
NAMP (1992)	US	2496	869-894; 824-849	10
NMT-450 (1981)	Scandinavia	180	463-467.5; 453-457.5	25
NMT-900 (1986)	Scandinavia	1999	935-960; 890-915	12.5
ETACS (1985)	U.K.	1000	935-960; 890-915	25
C-450 (1985)	Germany	222	461-466; 451-456	20
NTT (1979)	Japan	600	870-885; 925-940	25
JTACS (1988)	Japan	400	860-870; 915-925	25
NTACS (1993)	Japan	1040	843-846,860-870; 898-901, 915-925	12.5

*Tx: BS = Transmission band for base station and Tx: MS = Transmission band for mobile station

5. The Second Generation (2G)

Evolution from 1G to 2G was so distinct that made 1G standards became obsolete. Due to advance technologies of integrated circuits, 2G standards are all digital. Digital communications have many benefits resulted from source coding and channel coding yielding efficient use of the radio spectrum, integration of voice, video and data services as well as enhanced security systems. With digital systems, one can have more private on conversations, cellular fraud protection and special features such as caller ID. 2G cellular systems began to be deployed throughout the world in the early 1990s [12]. Classified by their multiple access techniques, 2G standards relied on time division multiple access (TDMA)/FDD and code division multiple access (CDMA)/FDD. Each user in FDMA systems is assigned a separate frequency to transmit. In TDMA, several users share the same frequencies in different time slots. CDMA accesses each user using different code sequences having wideband. A benefit of the CDMA-based approach is that frequencies are reusable in adjacent cells while TDMA requires a reuse pattern.

With a goal of seamless roaming in all countries, the Pan-European GSM (Global System for Mobile) [13] was developed by the European Telecommunications Standard Institute (ETSI) to union 1G analog systems existing in Europe. GSM uses TDMA to accommodate up to eight users on each 200 kHz radio channel. Over 70% of the worldwide mobile subscribers use GSM especially in Europe, Asia, Australia, South America and US (in the PCS spectrum band only) more than 110 countries [14].

Personal Communication System (PCS) is a cellular-like system operating at 1.8-1.9 GHz instead of 800-900 MHz for cellular.

In the US, 2G evolution began when the Cellular Telecommunication Industry Association (CTIA) requested the TIA to design a system that retrofitted into the existing AMPS system [15]. In 1992, the TR 45.3 technical subcommittees of the TIA introduced the IS-54 (Interim Standard). Later it was developed to IS-136 in 1996. IS-136 is known as North American Digital Cellular (NADC) whose some aspects are shown in Table 2. TDMA is used to support three users on each 30 kHz bandwidth. It has been deployed in North and South America and Australia (in both the cellular and PCS bands).

Table 2 Second generation cellular telephone systems

Standards **Country (Year introduced)**	GSM Europe (1990)	IS-136 US (1991)	IS-95 US (1993)	PDC Japan (1993)
Access method/Duplexing	TDMA/FDD	TDMA/FDD	CDMA/FDD	TDMA/FDD
Tx: BS (MHz)(Cellular bands) **(PCS bands)**	935-960 1805-1880;1930-1990	869-894 1930-1990	869-894 1930-1990	940-956 1429-1453
Tx: MS (MHz) (Cellular bands) **(PCS bands)**	890-915 1710-1785;1850-1910	824-849 1850-1910	824-849 1850-1910	810-826 1477-1501
Channel bandwidth (kHz)	200	30	1250	25
Number of duplex channels	125	832	20	1600
Mobile unit maximum power (W)	20	3	0.2	3
Users per channel	8	3	64	3
Modulation	GMSK	π/4 DQPSK	QPSK	π/4 DQPSK
Carrier bit rate (kbps)	270.8	48.6	9.6	42
Speech coder	RPE-LTP	VSELP	QCELP	VSELP
Speech coding bit rate (kbps)	13	8	8,4,2,1	6.7
Frame size (ms)	4.6	40	20	20
Convolutional error control coding	$^1/_2$ rate	$^1/_2$ rate	$^1/_2$ forward, 1/3 reverse	$^1/_2$ rate

*GMSK: Gaussian minimum shift keying; DQPSK: differential quadrature phase shift keying; RPE-LTP: regular pulse excitation-long term prediction; VSELP: vector sum excited linear prediction filter; QCELP: Qualcomm's codebook excited linear prediction.

Opposite to the attempt of European standard convergence, 2G standards in the US is diverged. Another standard, CDMA-based IS-95, was approved in July 1993 by the TR45.5 subcommittees of the TIA. It is known *as cdmaOne* to differentiate it from 3G-CDMA systems. Up to 64 downlink users share the same 1.25 MHz channel width. Soft handoff to improve voice quality and RAKE receiver to solve multipath fading are used. Due to the virtues of CDMA, it becomes a more popular choice for many carriers in North America (in both cellular and PCS bands), Korea, Japan, China, South America and Australia.

Also in the US, new specialized mobile radio (SMR) frequencies [2] in the 800 MHz band was gathered in the early 1990s to compete with the US cellular systems. The Integrated Digital Enhanced Network (iDEN) system, developed by Motorola in 1995, uses SMR and TDMA to accommodate up to 3 users in each 25 kHz channel. Its services integrate voice dispatch, cellular phone service, messaging and data transmission as well as protocol for a virtual private network. Meanwhile in Japan, the Pacific Digital Cellular (PDC) relies on TDMA to support three users of 25 kHz bandwidth in 800 and 1500 MHz bands [16].

For the transition from 1G to 2G, their compatibility was needed. Consequently, most wireless service companies offer dual-mode or triple-mode handset phones such that the users are able to roam other services. For example, purchasing a triple-mode phone, one can use CDMA in both cellular and PCS bands in additional to analog 1G cellular system for roaming anywhere in Canada, USA or Mexico. Dual-mode phones are also available for GSM900 and GSM1800 or triple-mode for added GSM1900. Moreover, 2G digital cellular is mobile assisted handoff (MAHO) that facilitates faster than that of cellular 1G.

6. Evolution to 2.5G

Developed from the voice-centric to data-centric standards, the half shift from 2G to 2.5G was to promote multimedia services before existing 3G. Multimedia communications mean communications of multiple information, a combination of text, data, graphics, animations, voice, sound, speech and still or moving images. Interaction between communicating users in personal and professional applications, such as teleworking, teleshopping, teletraining, emergency services, supports for handicapped, is a future plan. Even with small user data rates, GSM has been offering short messaging service (SMS) since 1993, limited to messages containing less than 160 characters [16]. Widespread uses of Internet motivate the demand for mobile Internet access. The first mobile Internet applications in GSM use Wireless Applications Protocol (WAP) of 9.6 kbps [17]. Before the introduction of WAP, NTT DoCoMo succeeded to convince iMode over 30 million Japanese subscribers in Jan. 2002.

iMode was designed to PDC networks in 1998 with 9.6 kbps data transmission rate to support games, color graphics and interactive web page browsing [2] [16] [17].

An attempt to retrofit 2.5G to 2G was made to obtain small (as possible) changes of infrastructures and handsets. TDMA-based and CDMA-based upgrade paths will be next described. The three TDMA upgrade options for GSM and IS-136 includes (a) High Speed Circuit Switched Data (HSCSD), (b) General Packet Radio Service (GPRS) and (c) Enhanced Data Rates for GSM Evolution (EDGE). IS-95B is the only upgrade path of IS-95. These options provide high speed data access to support the new Internet-ready cell phones for 3G.

● HSCSD [18] for 2.5G GSM (in 1999): HSCSD is a circuit switched transmission with relaxed channel coding. In addition, HSCSD pools consecutive time slots instead of limiting individual data users to only one specific time slot. It enables higher data rate from original 9.6 kbps to 14.4 kbps and up to 57.6 kbps by using up to four consecutive time slots. Due to circuit switching, HSCSD is well suited for dedicated streaming Internet access or real-time interaction and simply requires software upgrade at the existing GSM base stations.

● GPRS [18] [19] for 2.5G GSM and IS-136 (in 2000): "Always on" GPRS uses a packet switching to support users sharing individual radio channel and time slot and sending or receiving data at anytime. Voice call and data transfer can be done simultaneously. Data rate can speed as much as 171.2 kbps per user when all eight time slots of a GSM radio channel are dedicated to GPRS. GPRS network is ideal for non-real time Internet usage including the retrieval of e-mail, faxes and asymmetric data transfer between uplink and downlink. The implementation requires new routers and Internet gateways at the base stations and software to redefine air interface in order to handle a large number of bursty packets.

● EDGE [20] for 2.5G GSM and IS-136 (in 2001): EDGE is an enhanced GPRS by introducing a new radio modulation scheme, 8-PSK (phase shift keying) that requires triple bandwidth used by GPRS. Nine different air interface formats known as multiple modulation and coding scheme (MCS) are selectable to obtain best radio connection depending on the instantaneous demands of the network and the operating conditions as well as radio propagation conditions. Link adaptation and incremental redundancy select minimum required coding, modulation bandwidth, and power to obtain an acceptable link quality. A single GSM radio channel dedicated to EDGE is able to achieve data rates at 384 kbps/user. Note that with 8-PSK modulation and no coding and all eight time slots, EDGE provides 547.2 kbps/user [2]. This option needs new hardware and software at the exiting base stations.

● IS-95B [12] for 2.5G CDMA (in 1997): provides high speed packet/circuit switched data access on a common CDMA radio channels. It supports medium-data-rate services up to 115.2 (8x14.4) kbps by allowing 8 CDMA channels to a dedicated user [2]. In practice, using up to 7 Walsh codes, 64 kbps data rate is possible to a single user. Prior to IS-95B, IS-95A offers throughput limited to only 14.4 kbps. Moreover, soft handoff is deployed such that subscriber units can rapidly tune to different candidate base stations without instructions from the switch through the serving base station. IS-95B CDMA specifications require only new software in the base station controllers.

7. The Third Generation (3G)

The third generation mobile cellular systems started since the late of 2001 and is presently ongoing [17]. 3G system is intended to consolidate the 2.5G systems into a seamless radio infrastructure offering multimedia services on the move and global roaming with the quality as wired telecommunications. With this goal, the International Telecommunication Union Radio Communication Standardization Sector (ITU-R) planned to implement a global frequency band in the 2000 MHz range. It was initially called the Future Public Land Mobile Telecommunications System (FPLMTS) and renamed as International Mobile Telephone 2000 (IMT-2000) in the year of 2000. A call for proposal for IMT-2000 radio interface standardizes the following key features [12]:

● Use a common global frequency band for both terrestrial and satellite transmissions. According to WARC'92 (World Administrative Radio Conference in 1992), 1885-2025 MHz and 2110-2200 MHz are for IMT-2000 including 1980-2010 MHz and 2170-2200 MHz for the mobile satellite transmission. Later, WRC2000 allocated extension bands which are 806-960, 1710-1885 and 3500-2690 MHz [1] [21] [22]. One physical restriction is that rain attenuation for the radio wave is proportional to frequency.

● Use a small pocket terminal capable of global roaming for circuit & packet switches.

● Use TDD for small cells (low mobility) to suit asymmetric data services while FDD is for large cells (high mobility) or symmetric data services.

● Universal accesses for mobile communication systems with broadband capability: cordless, cellular, satellite, paging and private mobile radio systems.

● User data rates are specified as follows: satellite environment: 9.6 kbps; vehicle environment: 144 kbps; pedestrian: 384 kbps and indoor office: 2.048 Mbps.

Table 3 3G cellular phone standards

Proposal (Description)	Organization	Operations
DECT (Digital Enhanced Cordless Telecommunications)	ETSI Project DECT	1150-3456 kbps TDMA/TDD
cdma 2000 (Wideband CDMA (IS-95))	USA TIA TR45.5	DS-CDMA N×1.2288 Mcps (N=1,3,6,9,12) FDD/TDD
UTRA (UMTS Terrestrial Radio Access)	ETSI SMG2	
W-CDMA/NA (Wideband CDMA/North America)	USA T1P1-ATIS	DS-CDMA N×0.960 Mcps
W-CDMA	Japan ARIB	(N=4,8,16) FDD/TDD
CDMA II (Asynchronous DS-CDMA)	S. Korea TTA	DS-CDMA= Direct Sequence
WIMS/W-CDMA (Wireless multimedia and messaging service)	USA TIA TR46.1	CDMA
CDMA I (Multiband synchronous DS-CDMA)	S. Korea TTA	DS-CDMA N×0.9216 Mcps (N=1,4,16) FDD/TDD
UWC-136 (Universal Wireless Communications)	USA TIA TR45.3	TDMA outdoor: 722.2 kbps indoor: 5.2 Mbps FDD/TDD
TD-SCDMA (Time-division synchronous CDMA)	China CATT	DS-CDMA 1.1136 Mcps

By the end of June 1998, ITU-R received 10 proposals from several countries on the IMT-2000 terrestrial components as listed in Table 3. Note that the standards have a change of service from voice to mobile multimedia and include techniques of the adaptive antennas and diversities to enhance the system performance, capacity and coverage. Air interface specifications for 3G proposals can be found in [12][21]. The European Telecommunications Standards Institute (ETSI), Association of Radio Industries and Business (ARIB) in Japan, Telecommunications Technology Association (TTA) in South Korea, and the China Academy of Telecommunications Technology (CATT) have all developed standards known as Wideband CDMA (WCDMA) based on backward compatibility with GSM/IS-136/PDC. The Telecommunications Industry Association (TIA) in the United States proposed a standard called *cdma2000* based on backward compatibility with IS-95. The ITU-IMT 2000 organization is currently split into two camps: 3GPP and 3GPP2 (3G Partnership Project for WCDMA and for *cdma2000*, respectively).

● WCDMA standard [23] is now called the Universal Mobile Telecommunications Service (UMTS) [9]. It is a merge of competing wideband CDMA proposal and UMTS Terrestrial Radio Access (UTRA). Operating in 5 MHz of bandwidth, WCDMA in FDD mode supports packet data rates up to 2.048 Mbps per stationary user and in excess of 8 Mbps in the future [9]. In TDD mode, TD-SCDMA is deployed with 1.6 MHz bandwidth and low-chip rate carrier to provide data rates up to 2 Mbps. The technical specifications are phased as the following releases [16]: 3GPP release3 was issued in March 2000, defining FDD and TDD modes based on asynchronous transfer mode (ATM). 3GPP release 4 was issued in March 2001, relating a new version of TDD and FDD mode improvements. 3GPP release 5 was scheduled in March 2002, including IP-based transport. Since WCDMA requires completely new base station equipment, WCDMA will be fully installed expectedly by 2010-2015. Note that 3G service of NTT DoCoMo is called FOMA which was commercialized in October 2001. Elsewhere, the first 3G UMTS will be in services during 2003.

● An evolution of *cdmaOne is cdma2000* [2] [16]. It has two versions, cdma2000 1xRTT and cama2000 3xRTT (Radio Transmission Technology). Cdma2000 1x uses the same 1.25 MHz bandwidth as *cdmaOne* to support packet data service up to 144 kbps. Cdma2000 3x combines three channels into 3.75 MHz bandwidth to provide packet data rate in excess of 2 Mbps/user. An extension of the standardization 3GPP2 is cdma2000 1xEV-DO (Evolutionary Data Only) as known as high rate packet data (HRPD). This specifications were completed in 2001 by Qualcomm to provide up to 2.4 Mbps on the downlink but only 153 kbps on the uplink. The next phase of the 1x evolution known as cdma2000 1xEV-DV (Data and Voice) can offer data rates from 144 kbps and promising up to 3 Mbps. It introduces an all-IP architecture for radio access and core network and will be completed in 2003.

Since *cdma2000* uses the same spectrum, bandwidth, RF equipments and air interface framework, the upgrade path for IS-95 would be more seamless and less expensive than WCDMA. Note that an agreement between Ericsson for WCDMA and Qualcomm for cdma2000 has brought a convergence for these two standards into a single one [3].

8. The Fourth Generation (4G)

While 3G is nearing worldwide deployed, new visions beyond 3G have emerged in literatures [1][15][18][22][23][25]-[28]. Pervasiveness of IP (Internet Protocol) and the success of wireless networks suggest an Internet-oriented wireless communications systems which would be a trend of the existing 4G. It turned out that there is no single radio interface for existed 3G systems. Therefore, 4G must evolve the 3G in that a multiplicity of devices, including IP-enabled home appliances, vehicles, personal computers, sensors, actuators can be globally connected, capable of roaming and seamless interworking among different air interfaces. To meet the needs, the perspectives of the future 4G are summarized as follows:

● An all-IP system to interoperate over heterogeneous mobile/fixed wireless networks i.e. access convergence of the following layers. ***Distribution layer:*** (examples) broadcasting systems (e.g. satellite, DVB, DAB digital video/audio broadcasting), ***Cellular layer:*** cellular mobile systems (e.g. IMT-2000, GSM), ***Hot spot layer*** (company, campus, conference center, airport): WLAN-type systems (e.g. ETSI BRAN HIPERLAN2, HIPERACCESS and IEEE 802.11a), ***Personal network layer:*** systems for short-range connectivity (e.g. Bluetooth, DECT), cordless systems, ***Fixed (wired) layer:*** cable systems (e.g. ISDN, xDSL digital subscriber line).

Using an IP-based core network, the interworking between different and the same layers is possible in an optimal way to reduce data congestion and to save service fees, etc.

● Reconfigurable software radio [28] based wireless terminals for easy migration between systems. Intelligent terminals support multimode and multiband features based on software defined by radio concepts to achieve the best usage comfort, minimum cost, low power consumption and reasonable size. For instance, we can use TV broadcasting signals rather than regenerating high quality TV pictures via cellular networks due to the sake of smart terminal [26]. The terminals would have a camera, a screen for video and high resolution Internet applications, and also systems for short range connectivity for ad hoc networking with other devices [17][21]. That means one should have seamless accessed to all services regardless of location and terminal types.

● BRAIN (Broadband Radio Access for IP based Network) wide bandwidth makes it possible of *high data rate at high mobility* and multimedia services. The data rate is expected to be more than 2 Mbps in vehicular and 10 to 20 and up to 155 Mbps in stationary and pedestrians environments, respectively [22][27].

● Ad hoc or self-organizing networks: for example, direct mobile to mobile calls will be possible without using base stations [22].

● Cell size corresponds to mobility: Small cell: low mobility, Large cell: high mobility

● Sophisticated signal processing algorithms -for source compression to increase the user data rate and to obtain efficient transport of multimedia data, -for modulation and channel coding to enhance spectrum efficiency, -for smart antennas to improve link quality and channel capacity including -for the space-division multiple access (SDMA) concept to use the same frequency channels simultaneously for different users in distinct directions.

● Security of data transmission with authentication, authorization, and accounting (AAA)

● Easy to use and self explanatory -even handicapped and elderly people- to access advanced services with a quality as the wireline access.

With this flexible mobile radio access, expectedly, more handsets than PCs will be connected to the Internet around 2004. Meanwhile, NTT Do Co Mo in Japan has introduced the fifth generation for the year 2010 as the concept of *MAGIC:* Mobile multimedia, Anytime, anywhere, anyone, Global mobility support, Integrated wireless solution, and Customized personal service [1].

9. Conclusions

A seamless combination of mobile stations and multimedia has become true through generations of wireless systems. A survey of wireless communication evolution since the AM mobile system until the present 3G deployment is given. It began with the voice-oriented services in 1G. The comparison of 1G air interfaces reveals a variety of existed standards and inefficient use of spectrum. Technological improvement had driven toward digital 2G with significant evolution over 1G. Data-centric 2G standards support higher data rates from the SMS deriving to 2.5G. Both 1G and 2G took a decade to get mature. Global communications of 3G standards shrink the world into a more unified information society. A future direction beyond 3G focuses on the “user” for “Internet on the Air”. The main goal of 4G is to provide a seamless integration of mobile multimedia services into an IP-based single global network infrastructure with an intelligent terminal supporting multimode accesses possible by reconfigurable software radio.

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