 ISSN : 2230-7109(Online) | ISSN : 2230-9543(Print)

Evolution of Mobile Wireless Communication Networks: 1G to 4G

Amit Kumar[1]; Dr. Yunfei Liu[2]; Dr. Jyotsna Sengupta[3]; Divya[4]

[1,2]College of Information Science and Technology, Nanjing Forestry University, Nanjing, China

[3]Dept. of Computer Science, Punjabi University, Patiala, Punjab, India

[4]Dept. of ECE, CGC Group of Colleges, Gharuan, Mohali, Punjab, India

E-mail : amit.nfu@gmail.com

Abstract

Mobile communications systems revolutionized the way people communicate, joining together communications and mobility. A long way in a remarkably short time has been achieved in the history of wireless. Evolution of wireless access technologies is about to reach its fourth generation (4G). Looking past, wireless access technologies have followed different evolutionary paths aimed at unified target: performance and efficiency in high mobile environment. The first generation (1G) has fulfilled the basic mobile voice, while the second generation (2G) has introduced capacity and coverage. This is followed by the third generation (3G), which has quest for data at higher speeds to open the gates for truly "mobile broadband" experience, which will be further realized by the fourth generation (4G). The Fourth generation (4G) will provide access to wide range of telecommunication services, including advanced mobile services, supported by mobile and fixed networks, which are increasingly packet based, along with a support for low to high mobility applications and wide range of data rates, in accordance with service demands in multiuser environment. This paper provides a high level overview of the evolution of Mobile Wireless Communication Networks from 1G to 4G.

Keywords

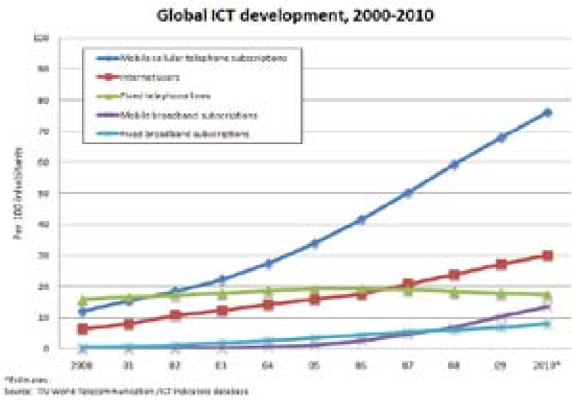
Mobile Wireless Communication Networks, 1G, 2G, 3G, 4G, Mobile Broadband

I. Introduction

The last few years have witnessed a phenomenal growth in the wireless industry, both in terms of mobile technology and its subscribers. There has been a clear shift from fixed to mobile cellular telephony, especially since the turn of the century. By the end of 2010, there were over four times more mobile cellular subscriptions than fixed telephone lines (see Fig. 1). Both the mobile network operators and vendors have felt the importance of efficient networks with equally efficient design. This resulted in Network Planning and optimization related services coming in to sharp focus [1, 7].

With all the technological advances, and the simultaneous existence of the 2G, 2.5G and 3G networks, the impact of services on network efficiency have become even more critical. Many more designing scenarios have developed with not only 2G networks but also with the evolution of 2G to 2.5G or even to 3G networks. Along with this, inter-operability of the networks has to be considered [2].

1G refers to analog cellular technologies; it became available in the 1980s. 2G denotes initial digital systems, introducing services such as short messaging and lower speed data. CDMA2000 1xRTT and GSM are the primary 2G technologies, although CDMA2000 1xRTT is sometimes called a 3G technology because it meets the 144 kbps mobile throughput requirement. EDGE, however, also meets this requirement. 2G technologies became available in the 1990s. 3G requirements were specified by the ITU as part of the International Mobile Telephone 2000 (IMT-2000) project, for which digital networks had to provide 144 kbps of throughput at mobile speeds, 384 kbps at pedestrian speeds, and 2 Mbps in indoor environments. UMTS-HSPA and CDMA2000 EV-DO are the primary 3G technologies, although recently WiMAX was also designated as an official 3G technology. 3G technologies began to be deployed last decade.



Source: ITU World Telecommunication/ICT Indicators database.

Fig. 1: Global ICT Developments, 2000-2010 [1]

The ITU has recently issued requirements for IMT-Advanced, which constitutes the official definition of 4G. Requirements include operation in up-to-40 MHz radio channels and extremely high spectral efficiency. The ITU recommends operation in up-to-100 MHz radio channels and peak spectral efficiency of 15 bps/Hz, resulting in a theoretical throughput rate of 1.5 Gbps. Previous to the publication of the requirements, 1 Gbps was frequently cited as a 4G goal. No available technology meets these requirements yet. It will require new technologies such as LTE-Advanced (with work already underway) and IEEE 802.16m. Some have tried to label current versions of WiMAX and LTE as "4G", but this is only accurate to the extent that such designation refers to the general approach or platform that will be enhanced to meet the 4G requirements. With WiMAX and HSPA significantly outperforming 3G requirements, calling these technologies 3G clearly does not give them full credit, as they are a generation beyond current technologies in capability. But calling them 4G is not correct. Unfortunately, the generational labels do not properly capture the scope of available technologies and have resulted in some amount of market confusion [10].

II. Evolution of Mobile Cellular Networks

Mobile Cellular Network evolution has been categorized in to 'generations' as shown in Fig. 2 [3].

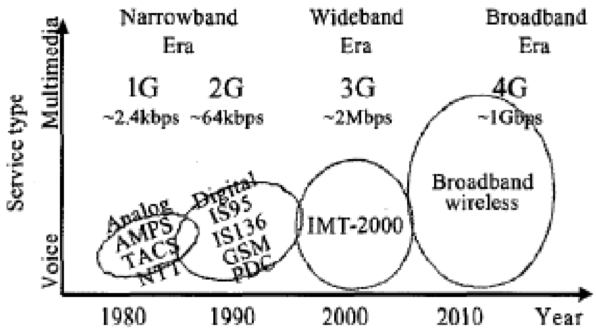


Fig. 2: Evolution of Mobile Cellular Networks [11]

A brief overview on each generation is given below.

A. The First Generation System (Analog)

In 1980 the mobile cellular era had started, and since then mobile communications have undergone significant changes and experienced enormous growth. Fig. 2 shows the evolution of the mobile networks. First-generation mobile systems used analog transmission for speech services. In 1979, the first cellular system in the world became operational by Nippon Telephone and Telegraph (NTT) in Tokyo, Japan. Two years later, the cellular epoch reached Europe. The two most popular analogue systems were Nordic Mobile Telephones (NMT) and Total Access Communication Systems (TACS). Other than NMT and TACS, some other analog systems were also introduced in 1980s across the Europe. All of these systems offered handover and roaming capabilities but the cellular networks were unable to interoperate between countries. This was one of the inevitable disadvantages of first-generation mobile networks.

In the United States, the Advanced Mobile Phone System (AMPS) was launched in 1982. The system was allocated a 40-MHz bandwidth within the 800 to 900 MHz frequency range by the Federal Communications Commission (FCC) for AMPS. In 1988, an additional 10 MHz bandwidth, called Expanded Spectrum (ES) was allocated to AMPS. It was first deployed in Chicago, with a service area of 2100 square miles^2. AMPS offered 832 channels, with a data rate of 10 kbps. Although Omni directional antennas were used in the earlier AMPS implementation, it was realized that using directional antennas would yield better cell reuse. In fact, the smallest reuse factor that would fulfill the 18db signal-to-interference ratio (SIR) using 120-degree directional antennas was found to be 7. Hence, a 7-cell reuse pattern was adopted for AMPS. Transmissions from the base stations to mobiles occur over the forward channel using frequencies between 869-894 MHz. The reverse channel is used for transmissions from mobiles to base station, using frequencies between 824-849 MHz.

AMPS and TACS use the frequency modulation (FM) technique for radio transmission. Traffic is multiplexed onto an FDMA (frequency division multiple access) system [5, 3].

B. The Second-generation & Phase 2+ Systems (Digital)

Second-generation (2G) mobile systems were introduced in the end of 1980s. Low bit rate data services were supported as well as the traditional speech service. Compared to first-generation systems, second-generation (2G) systems use digital multiple access technology, such as TDMA (time division multiple access) and CDMA (code division multiple access). Consequently, compared with first-generation systems, higher spectrum efficiency, better data services, and more advanced roaming were offered by 2G systems. In Europe, the Global System for Mobile Communications (GSM) was deployed to provide a single unified standard. This enabled seamless services through out Europe by means of international roaming. Global System for Mobile Communications, or GSM, uses TDMA technology to support multiple users During development over more than 20 years, GSM technology has been continuously improved to offer better services in the market. New technologies have been developed based on the original GSM system, leading to some more advanced systems known as 2.5 Generation (2.5G) systems.

In the United States, there were three lines of development in second-generation digital cellular systems. The first digital system, introduced in 1991, was the IS-54 (North America TDMA Digital Cellular), of which a new version supporting additional services (IS-136) was introduced in 1996. Meanwhile, IS-95 (CDMA One) was deployed in 1993. The US Federal Communications Commission (FCC) also auctioned a new block of spectrum in the 1900 MHz band (PCS), allowing GSM1900 to enter the US market. In Japan, the Personal Digital Cellular (PDC) system, originally known as JDC (Japanese Digital Cellular) was initially defined in 1990 [3].

Since the first networks appeared at the beginning of the 1991, GSM gradually evolved to meet the requirements of data traffic and many more services than the original networks. GSM (Global System for Mobile Communication): The main element of this system are the BSS (Base Station Subsystem), in which there are BTS (Base Transceiver Station) and BSC (Base Station Controllers); and the NSS (Network Switching Subsystem), in which there is the MSC (Mobile Switching Centre); VLR (Visitor Location Register); HLR (Home Location Register); AC (Authentication Centre) and EIR (Equipment Identity Register). This network is capable of providing all the basic services up to 9.6kbps, fax, etc. This GSM network also has an extension to the fixed telephony network. A new design was introduced into the mobile switching center of second-generation systems. In particular, the use of base station controllers (BSCs) lightens the load placed on the MSC (mobile switching center) found in first-generation systems. This design allows the interface between the MSC and BSC to be standardized. Hence, considerable attention was devoted to interoperability and standardization in second-generation systems so that carrier could employ different manufacturers for the MSC and BSCs. In addition to enhancements in MSC design, the mobile-assisted handoff mechanism was introduced. By sensing signals received from adjacent base stations, a mobile unit can trigger a handoff by performing explicit signaling with the network. GSM and VAS (Value Added Services): The next advancement in the GSM system was the addition of two platforms, called Voice Mail Service (VMS) and the Short Message Service Centre (SMSC). The SMSC proved to be incredibly commercially successful, so much so that in some networks the SMS traffic constitutes a major part of the total traffic. Along with VAS, IN (Intelligent services) also made its mark in the GSM system, with its advantage of giving the operators the chance to create a whole range of new services. Fraud management and 'pre-paid' services are the result of the IN service.

GSM and GPRS (General Packet Radio Services): As requirement for sending data on the air-interface increased, new elements such as SGSN (Servicing GPRS) and GGSN (Gateway GPRS) were added to the existing GSM system. These elements made it possible to send packet data on the air-interface. This part of the network handling the packet data is also called the 'packet core network'. In addition to the SGSN and GGSN, it also contains the IP routers, firewall servers and DNS (Domain Name Servers). This enables wireless access to the internet and bit rate reaching to 150 kbps in optimum conditions. The move into the 2.5G world began with General Packet Radio Service (GPRS). GPRS is a radio technology for GSM networks that adds packet-switching protocols, shorter setup time for ISP connections, and the possibility to charge by the amount of data sent, rather than connection time. Packet switching is a technique whereby the information (voice or data) to be sent is broken up into packets, of at most a few Kbytes each, which are then routed by the network between different destinations based on addressing data within each packet. Use of network resources is optimized as the resources are needed only during the handling of each packet. GPRS supports flexible data transmission rates as well as continuous connection to the network. GPRS is the most significant step towards 3G. GSM and EDGE (Enhanced Data rates in GSM Environment): With both voice and data traffic moving on the system, the need was felt to increase the data rate. This was done by using more sophisticated coding methods over the internet and thus increasing the data rate up to 384 kbps. Implementing EDGE was relatively painless and required relatively small changes to network hardware and software as it uses the same TDMA (Time Division Multiple Access) frame structure, logic channel and 200 kHz carrier bandwidth as today's GSM networks. As EDGE progresses to coexistence with 3G WCDMA, data rates of up to ATM-like speeds of 2 Mbps could be available [5, 2]. Nowadays, second-generation digital cellular systems still dominate the mobile industry throughout the whole world. However, third generation (3G) systems have been introduced in the market, but their penetration is quite limited because of several techno-economic reasons.

C. The Third-generation (WCDMA in UMTS, CDMA2000 & TD-SCDMA)

In EDGE, high-volume movement of data was possible, but still the packet transfer on the air-interface behaves like a circuit switch call. Thus part of this packet connection efficiency is lost in the circuit switch environment. Moreover, the standards for developing the networks were different for different parts of the world. Hence, it was decided to have a network which provides services independent of the technology platform and whose network design standards are same globally. Thus, 3G was born [2]. The International Telecommunication Union (ITU) defined the demands for 3G mobile networks with the IMT-2000 standard. An organization called 3rd Generation Partnership Project (3GPP) has continued that work by defining a mobile system that fulfills the IMT-2000 standard. In Europe it was called UMTS (Universal Terrestrial Mobile System), which is ETSI-driven. IMT2000 is the ITU-T name for the third generation system, while cdma2000 is the name of the American 3G variant. WCDMA is the air-interface technology for the UMTS. The main components includes BS (Base Station) or nod B, RNC (Radio Network Controller), apart from WMSC (Wideband CDMA Mobile Switching Centre) and SGSN/GGSN. 3G networks enable network operators to offer users a wider range of more advanced services while achieving greater network capacity through improved spectral efficiency. Services include wide-area wireless voice telephony, video calls, and broadband wireless data, all in a mobile environment. Additional features also include HSPA (High Speed Packet Access) data transmission capabilities able to deliver speeds up to 14.4 Mbps on the downlink and 5.8 Mbps on the uplink.

The first commercial 3G network was launched by NTT DoCoMo in Japan branded FOMA, based on W-CDMA technology on October 1, 2001 [8]. The second network to go commercially live was by SK Telecom in South Korea on the 1xEV-DO (Evolution-Data Optimized) technology in January 2002 followed by another South Korean 3G network was by KTF on EV-DO in May 2002. In Europe, the mass market commercial 3G services were introduced starting in March 2003 by 3 (Part of Hutchison Whampoa) in the UK and Italy. This was based on the W-CDMA technology. The first commercial United States 3G network was by Monet Mobile Networks, on CDMA2000 1x EV-DO technology and the second 3G network operator in the USA was Verizon Wireless in October 2003 also on CDMA2000 1x EV-DO. The first commercial 3G network in southern hemisphere was launched by Hutchison Telecommunications branded as Three using UMTS in April 2003. The first commercial launch of 3G in Africa was by EMTEL in Mauritius on the W-CDMA standard. In North Africa (Morocco), a 3G service was provided by the new company Wana in late March 2006. Roll-out of 3G networks was delayed in some countries by the enormous costs of additional spectrum licensing fees. In many countries, 3G networks do not use the same radio frequencies as 2G, so mobile operators must build entirely new networks and license entirely new frequencies; an exception is the United States where carriers operate 3G service in the same frequencies as other services. The license fees in some European countries were particularly high, bolstered by government auctions of a limited number of licenses and sealed bid auctions, and initial excitement over 3G's potential. Other delays were due to the expenses of upgrading equipment for the new systems. Still several major countries such as Indonesia have not awarded 3G licenses and customers await 3G services. China delayed its decisions on 3G for many years. In January 2009, China launched 3G but interestingly three major companies in China got license to operate the 3G network on different standards, China Mobile for TD-SCDMA, China Unicom for WCDMA and China Telecom for CDMA2000 [2].

D. Fourth Generation (All-IP)

The emergence of new technologies in the mobile communication systems and also the ever increasing growth of user demand have triggered researchers and industries to come up with a comprehensive manifestation of the up-coming fourth generation (4G) mobile communication system [9]. In contrast to 3G, the new 4G framework to be established will try to accomplish new levels of user experience and multi-service capacity by also integrating all the mobile technologies that exist (e.g. GSM - Global System for Mobile Communications, GPRS - General Packet Radio Service, IMT-2000 - International Mobile Communications, Wi-Fi - Wireless Fidelity, Bluetooth) (see Fig. 3) [6].

The fundamental reason for the transition to the All-IP is to have a common platform for all the technologies that have been developed so far, and to harmonize with user expectations of the many services to be provided. The fundamental difference between the GSM/3G and All-IP is that the functionality of the RNC and BSC is now distributed to the BTS and a set of servers and gateways. This means that this network will be less expensive and data transfer will be much faster [2]. 4G will make sure - “The user has freedom and flexibility to select any desired service with reasonable QoS and affordable price, anytime, anywhere.” 4G mobile communication services started in 2010 but will become mass market in about 2014-15.

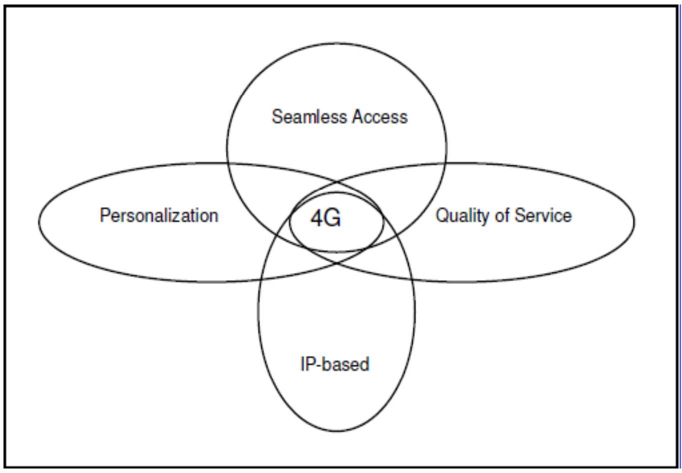


Fig. 3: The next Generation Mobile Communication Systems Features [9]

IMT-Advanced 4G standards will usher in a new era of mobile broadband communications, according to the ITU-R. IMT-Advanced provides a global platform on which to build next generations of interactive mobile services that will provide faster data access, enhanced roaming capabilities, unified messaging and broadband multimedia. According to ITU, "ICTs and broadband networks have become vital national infrastructure—similar to transport, energy and water networks—but with an impact that promises to be even more powerful and far-reaching. These key enhancements in wireless broadband can drive social and economic development, and accelerate progress towards achieving the United Nations' Millennium Development Goals, or MDGs." [12]. The current agreements on the requirements for IMT-Advanced are:

- Peak data rate of 1 Gbps for downlink (DL) and 500 Mbps for uplink (UL).
- Regarding latency, in the Control plane the transition time from Idle to Connected should be lower than 100ms. In the active state, a dormant user should take less than 10ms to get synchronized and the scheduler should reduce the User plane latency at maximum.
- Downlink peak spectral efficiency up to 15 bps/Hz and uplink peak spectral efficiency of 6.75 bps/Hz with an antenna configuration of 4 × 4 or less in DL and 2 × 4 or less in UL.
- The average user spectral efficiency in DL (with inter-site distance of 500m and pedestrian users) must be 2.2 bps/Hz/cell with MIMO 4× 2, whereas in UL the target average spectral efficiency is 1.4 bps/Hz/cell with MIMO 2 × 4.
- In the same scenario with 10 users, cell edge user spectral efficiency will be 0.06 in DL 4 × 2. In the UL, this cell edge user spectral efficiency must be 0.03 with MIMO 2 × 4.
- Mobility up to 350 km/h in IMT-Advanced.
- IMT-Advanced system will support scalable bandwidth and spectrum aggregation with transmission bandwidths more than 40MHz in DL and UL.
- Backward compatibility and inter-working with legacy systems.

After completion of its Release-8 specifications, Third Generation Partnership Project (3GPP) has already planned for a work item called LTE-Advanced to meet the IMT-Advanced requirements for 4G. Also, WiMAX Forum and IEEE are also evolving WiMAX through IEEE 802.16m or WiMAX-m to satisfy 4G requirements. Table 1 summarizes the generations of wireless technology.

Table 1: 1G to 4G [10].

Generation	Requirements	Comments
1G	No official requirements. Analog technology.	Deployed in the 1980s.
2G	No official requirements. Digital Technology.	First digital systems. Deployed in the 1990s. New services such as SMS and low-rate data. Primary technologies include IS-95 CDMA and GSM.
3G	ITU's IMT-2000 required 144 kbps mobile, 384 kbps pedestrian, 2 Mbps indoors	Primary technologies include CDMA2000 1X/ EVDO and UMTS-HSPA. WiMAX now an official 3G technology.
4G	ITU's IMT-Advanced requirements include ability to operate in up to 40 MHz radio channels and with very high spectral efficiency.	No technology meets requirements today. IEEE 802.16m and LTE-Advanced being designed to meet requirements.

III. Conclusion

The last few years have witnessed a phenomenal growth in the wireless industry. The ever increasing demands of users have triggered researchers and industries to come up with a comprehensive manifestation of the up-coming fourth generation (4G) mobile communication system. As the history of mobile communications shows, attempts have been made to reduce a number of Technologies to a single global standard. The first generation (1G) has fulfilled the basic mobile voice, while the second generation (2G) has introduced capacity and coverage. This is followed by the third generation (3G), which has quest for data at higher speeds to open the gates for truly "mobile broadband" experience, which will be further realized by the fourth generation (4G).

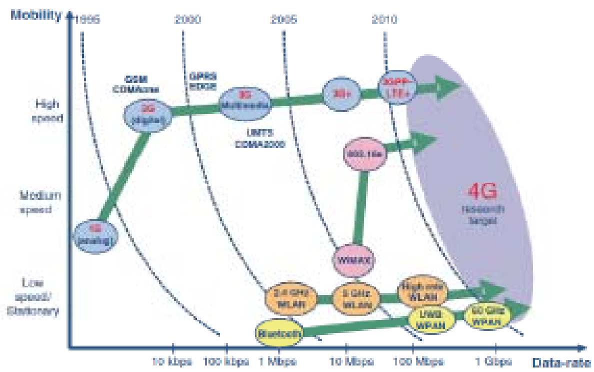


Fig 4: Plethora of emerging and legacy wireless standards [13]

The 4G network will encompass all systems from various networks, public to private; operator-driven broadband networks to personal areas; and ad hoc networks. The 4G systems will interoperate with 2G and 3G systems, as well as with digital (broadband) broadcasting systems. In addition, 4G systems will be fully IP-based wireless Internet which will provide access to wide range of telecommunication services, including advanced mobile services, supported by mobile and fixed networks, which are increasingly packet based, along with a support for low to high mobility applications and wide range of data rates, in accordance with service demands in multiuser environment (see fig.4). This paper provides a comprehensive overview of the evolution of Mobile Wireless Communication Networks from 1G to 4G.

IV. References

[1] ITU (2009). "Measuring the Information Society; The ICT Development Index", [Online] Available: http://www.itu.int/ITU-D/ict/publications/idi/2009/material/IDI2009_w5.pdf

[2] Mishra, Ajay K. "Fundamentals of Cellular Network Planning and Optimization, 2G/2.5G/3G...Evolution of 4G", John Wiley and Sons, 2004.

[3] Chen, Yue (2003). "Soft Handover Issues in Radio Resource Management for 3G WCDMA Networks", Queen Mary, University of London, [Online] Available: www.elec.qmul.ac.uk/research/thesis/YueChen2003.pdf

[4] ITU-R PDNR WP8F. "Vision, Framework and Overall Objectives of the Future Development of IMT-2000 and Systems beyond IMT-2000", 2002.

[5] Toh, C. K. "Ad Hoc Mobile Wireless Networks: Protocols and Systems", Prentice Hall, New Jersey, USA, 2002.

[6] Pereira, Vasco & Sousa, Tiago. "Evolution of Mobile Communications: from 1G to 4G", Department of Informatics Engineering of the University of Coimbra, Portugal 2004.

[7] ITU (2010). "Measuring the Information Society, 2010". [Online] Available: http://www.itu.int/ITU-D/ict/statistics/material/graphs/2010/Global_ICT_Dev_00-10.jpg

[8] UMTS World (2009). "UMTS / 3G History and Future Milestones", [Online] Available: http://www.umtsworld.com/umts/history.htm

[9] Kamarularifin Abd Jalil, Mohd Hanafi Abd. Latif, Mohamad Noorman Masrek, "Looking Into The 4G Features", MASAUM Journal of Basic and Applied Sciences Vol.1, No. 2 September 2009

[10] 3gamericas (2010). "Transition to 4G: 3GPP Broadband Evolution to IMT-Advanced", Rysavy Research/3G Americas. [Online] Available: www.rysavy.com/PR/3GA_PR_2010_09.pdf

[11] Fumiyuki Adachi, "Wireless past and Future: Evolving Mobile Communication Systems". IEICE Trans. Findamental, Vol. E84-A, No.1, January 2001.

[12] ITU (2010). "ITU Paves the Way for Next-Generation 4G Mobile Broadband Technologies". [Online] Available: http://www.itu.int/net/pressoffice/press_releases/2010/40.aspx

[13] Giannini,Vito; Craninckx,Jan; Baschirotto, Andrea, "Baseband Analog Circuits for Software Defined Radio", Springer, USA, 2008. ISBN: 978-1-4020-6537-8

Amit Kumar received his bachelor's degree in Mathematics from the Himachal Pradesh University, Shimla, India, in 2002 and Masters degree in Computer Application from Kurukshetra University, Kurukshetra, India, in 2006. He completed his M.Phil. in Computer Science from Annamalai University, Annamalainagar, Tamilnadu, India, in 2010. He is currently working as a Lecturer in the Department of Computer Science, College of Information Science and Technology, Nanjing Forestry University, Nanjing, China. He has many publications in National /International Conference proceedings and International Journals. He is a reviewer for many international Journals. His current interest includes Techno-Economic Analysis of Broadband Wireless Networks viz. WiMAX, HSPA, EV-DO and LTE. His future focus is to explore the Green Wireless Technologies and Sustainable development.

Yun-fei Liu was born in Nanjing, China, on December 20, 1962. He received the B.S. degree in physics from Zhenjiang Normal College, Zhenjiang, China, in 1984, the M.S. degree in optics from Sichuan Normal University, Chengdu, China, in 1991, and the Ph.D. degree in testing measuring technology and instrument from Nanjing University of Aeronautics and Astronautics, Nanjing, China, in 2005. He was a teaching assistant, lecturer, associate professor, with Department of Basic Courses, Nanjing Forestry University, in 1991, 1994 and 2000 respectively. He was an associate professor, professor, College of Information Science and Technology, Nanjing Forestry University, in 2000 and 2007 respectively. His research interests include digital signal processing, electronic measurement techniques, microwave and optical technique. At present, He is engaged in Gaussian optics and terahertz technique in forestry application.

Dr. Jyotsna Sengupta received her B.E. degree in Electronics and Communications, and her Ph.D. degree in Computer Science and Engineering from Thapar Institute of Engineering and Technology, Patiala, India, in 1982 and 2002, respectively. She received her M.S. in computer Science and Engineering from University of Santa Clara, California, USA, in 1985. She worked as a Software Engineer at EXL, Ltd., Sunnyvale, California, in 1985-86. During 1986-87, she worked in the Department of Computer Science, Delhi University, India. Since 1989, she has been in the faculty of Punjabi University, Patiala, India where She is currently a Reader and Head of the Department of Computer Science. Her current research interests primarily lie in the area of network security and secure computing.

Divya is persuing her B. Tech. in Electronics & Telecommunication Engineering from CGC Group of Colleges, Gharuan, Mohali, Punjab, India. Her current research interest is Sustainability of Mobile Broadband Networks.