3G MOBILE NETWORK TECHNOLOGIES AND EXPERIENCES

ABBAS JAMALIPOUR

MASAMI YABUSAKI

After great success of the second-generation (2G) wireless cellular systems during 1990s, telecommunications industry worldwide has started to work on an enhanced system that could magnify the service quality and data rates of the cellular systems several tens of times over. Those activities have been happening in parallel to an exponential increase in number of Internet users, and the significant popularity of Internet services and e-business. At the same time, the wireless technology has been introducing low-cost and high-speed interfaces such as wireless LAN and Bluetooth, all to initiate broadband data networking techniques that are easier and more affordable to home and office users. Third-generation (3G) wireless cellular systems thus have been developed in conjunction with observing experiences taken from their 2G counterparts as well as considerations of new needs coming from the emerging Internet-oriented applications.

Third-generation wireless systems enable users to enjoy high-speed mobile multimedia services anytime and anywhere globally. They follow the International Telecommunication Union (ITU) standard International Mobile Telecommunications-2000 (IMT-2000). "2000" originally implied three major features: a user bit rate up to 2000 kb/s (2 Mb/s), a frequency spectrum around the 2000 MHz (2 GHz) band, and a system to be deployed around the year 2000. However, unlike when the 2G systems were developed, 3G found its development path through a difficult economic situation overshadowing all industries as well as a rapid development pattern in other relevant technology sectors. On one hand, it has been revealed that the 10-year telecommunications development plan for a single generation is too long compared to other technological enhancements. In the wired fixed sector, broadband services with asymmetrical digital subscriber line (ADSL) up to 12 Mb/s and fiber to the home (FTTH) up to 100 Mb/s have been commercialized. This makes it difficult to convince mobile users that the 2 Mb/s bit rate offered by 3G is impressive enough compared to the 10–50 kb/s rates previously offered by 2G systems. As a result, the wireless LAN supporting 11 Mb/s has already been commercialized in limited hot spot and indoor areas. Also, high-speed cellular packet radio supporting 14.4 Mb/s, high-speed downlink packet access (HSDPA), has been developed. As the ITU provided additional frequency for IMT-2000, some countries will utilize such additional frequency other than 2 GHz for 3G systems. Even in some regions such as North America, the existing frequency spectrum for the 2G systems (i.e., 800/900 MHz) will be used for the 3G systems. On the other hand, the huge spectrum investment and slow production of 3G mobile phones have produced extra delay in starting the 3G deployments around the world.

From the mobile voice communications point of view, 2G cellular networks have provided quite sufficient and satisfactory services to users. Therefore, data services (especially at very high speeds), and particularly the mobile Internet, could be considered the main service component of 3G cellular systems. The main goal of 3G systems thus is to provide a reliable wireless Internet service to wide area mobile users. 2G networks have successfully provided low-data-rate services in the form of short message service (SMS) as well as through Cellular Digital Packet Data (CDPD) and High Speed Circuit Switched Data (HSCSD) networks. CDPD and HSCSD can be considered the first initiatives for providing wireless mobile Internet services over cellular networks. They have been developed as value-added services over 2G systems, and still provide services to many subscribers around the world despite the new technologies that utilize packet-switched concepts in their core networks. CDPD was designed to extend the existing wired data communication networks at the time. It allows data transmission between mobile and mobile, mobile and fixed, fixed and mobile packet exchange, and fixed and fixed users. Later this concept was utilized in PCS cellular systems. HSCSD was an answer to providing data services using the circuit-switched cellular network GSM in its Phase 2+. HSCSD allows a GSM mobile user to transmit at a data rate up to eight times higher than the usual 9.6 kb/s of GSM by attaining multiple time-division multiple access (TDMA) channels. Later the 2.5G successor of GSM, the General Packet Radio Service (GPRS) system used a different method, that is, using packet-oriented connections on the radio interface and within the core network, to provide high data rates to mobile stations but using only one channel.

Later, Wireless Application Protocol (WAP) and the Japan's i-mode tried to bring wireless Internet services over the cellular network even further. WAP has been designed to deal with not only the wireless channel limitations and shortcomings but also the boundaries of mobile device capabilities. Some limitations of a mobile device are the limited processing power of microprocessors inside mobile handsets, memory size and battery life of mobile devices, and the small and limited display resolution of mobile handset devices. WAP also had to be designed to make information be viewed easier than with a desktop computer viewer. i-mode is another important service initiated in recent years by Japan's cellular network provider, NTT DoCoMo. The service has revolutionized mobile services, and thanks to the great system features and business model used in i-mode, the service had more than 35 million subscribers by November 2002. This figure started to grow in 2000 when it was clear that no 3G wireless system would be functionally implemented in any part of the world soon; therefore, it can exhibit the advanced technologies already included in 2G cellular systems for providing such an upgraded mobile Internet service. i-mode provides mobile cellular users access to Internet contents such as email, Web browsing, mobile banking, Internet shopping, sport event and movie ticket booking, restaurant search, and similar services. The billing scheme used in the i-mode is based on pay per volume of data thanks to the innovative packet network, Personal Digital Cellular-Packet (PDC-P). i-mode is considered the first mobile Internet technology that supports packet switching, different from its predecessor circuit-switched cellular data networks, so it could change the billing scheme based on volume of data exchanged between the mobile data user and the network. i-mode is considered the always-on concept for Internet access, not dialup data access. This made the service very attractive for the majority of users who do not want to pay high mobile phone tariffs when they just occasionally exchange burst Internet data. The i-mode designers had a close collaboration in development of WAP 2.0, and look forward to a kind of convergence between the two mobile Internet technologies for a global mobile multimedia and Internet service. These mobile Internet services will be advanced with higher access speed in the 3G system.

The strong market demand for the 3G system was to offer attractive new services with minimum investment. This led a general policy for the IMT-2000 standardization and development, "Radio Revolution, Core Network (CN) Evolution." As a result, IMT-2000 formed a family standard in which member systems have a similar level of service capability with different signaling protocols and enable users to roam among them. Representative IMT-2000 family member standards are "W-CDMA + GSM evolved CN" and "cdma 2000 + ANSI-41 evolved CN." It is clear that the wireless telecommunication migration from2G systems into 3G systems, IMT-2000, is a huge step in development of wireless communications technology and there is no doubt it will encounter many implications and adjustments before it becomes an acceptable technology. Another recent initiative from the Japanese cellular company as the successor of i-mode is Freedom of Mobile Multimedia Access (FOMA) service. FOMA was named the start of 3G multimedia wireless technology in the world when it began in October 2001. FOMA is based on wideband code-division multiple access (CDMA) technology and GSM-evolved IMT-2000 CN. Full-motion video image transmission, music, and game distribution as well as other types of data services requiring high-speed large-capacity wireless media are supported in FOMA in addition to the services already supported by i-mode. A maximum of 384 kb/s data rate is considered on downlinks of FOMA, whereas uplinks support a maximum of 64 kb/s, in line with the asymmetric data transmission concept for future wireless networks.

Due to the importance of the topic, we have seen several special issues in different journals and magazines in the past few years where the 3G technology has been discussed. In this special issue we will look at real experiences and problems that wireless vendors as well as wireless operators have faced regarding 3G network implementations, in particular, the GSM-evolved IMT-2000 (or UMTS) network implementation and its operation and maintenance. As the Internet access traffic increases, the 3G network needs to be evolved further to efficiently deliver IP traffic and accommodate multiple radio access networks. This special issue also covers such further 3G evolution subjects. This special issue of *IEEE Wireless Communications* tries to gather related information on the topic of 3G system implementations around the world. The guest editors have tried to attract some major contributions from key industry players toward the realization of 3G and the wireless Internet in this special issue. Those contributions have been reviewed by experts from industry and academia in order to achieve a reliable edition of updated articles on this important topic for the magazine's readers. Since the guest editors are committed to include only articles that meet the strict technical standards of the magazine, some articles discussing other critical aspects of 3G implementations could not published in this special issue after the peer review process. The guest editors would like to thank authors of all articles submitted. While the standardization of 3G systems is almost completed, their implementation and practical adjustments have a long way to completion. Researchers in industry and academia have already started their investigations toward the next-generation mobile networks. Revealing implementation issues and experiences from industries involved in this significant technology evolution and upgrading will definitely assist those researchers to plan and design better systems for future generations. To meet such expectations of readers, this special issue has been organized in order of issues on the initial 3G to those for later phases. The first three articles describe practical design and experience in 3G networks. The next two articles deal with the emerging important issues such as roaming and IP address scarcity. The last two articles describe 3G network optimization and integration.

South Korea and Japan are unique countries in that they did not introduce GSM in their 2G cellular systems. All Korea's mobile operators have implemented ANSI-41-based 2G core networks, whereas the mobile operators in Japan have implemented the Japanese standard, PDC, core networks. Thus, they have several challenges in developing the evolved GSM-based 3G CN for dual operation with such 2G CNs. In the first article, "Design Policy of a GSM-Based IMT-2000 Network," Hideaki Yumiba, Koji Yamamoto, and Masami Yabusaki from NTT DoCoMo, Japan, describe the network design policy for the operation of 2G PDC and 3G GSM-based IMT-2000 networks. The article explains development of ATM switching, in particular ATM AAL2 switching, to transport low-bit-rate voice in the most efficient manner; implementation of number portability, alternative access, and identical supplementary services between 2G and 3G networks; and also discusses some key network techniques for circuit-switched and packet-switched roaming services. In the second article, "IMT-2000 Core Network Node Systems," Toshiyuki Tamura, Tomoya Takahashi, Takashi Morita, Koji Ohtaki, and Hideo Takeda from NEC, Japan, introduce the design of a 3G is mainly composed of ATM switch, HLR, and SCP. This article describes the implementation method of CAMEL to offer existing 2G supplementary services in 3G networks. In order to provide new attractive services flexibly without any impacts on 3G CN nodes, it also proposes a mobile Internet service architecture that consists of four layers: service, application, middleware, and platform. In the third article, "Interoperability between UMTS and cdma2000 Networks," by Soojin Kim, HyungJoon Cho, HeeHyeok Hahm, SangYun Lee, and MyungSung Lee from SK Telecom Co., proposes a network architecture based on the dual stack solutions that share some key network functions such as HLR, SCP, and SMC between UMTS and cdma2000 networks. This solution meets the primary requirements of users and operators: number portability and service transparency.

As 3G system deployments proceed around the world, the interest of users and operators will be shifted to more global roaming services. Roaming for voice, the ability of a user to make and receive calls when visiting another country, is now taken for granted in 2G systems. The fourth article, "Critical Issues for Roaming in 3G," by Anders Roos, Magnus Hartman, and Stephen Dutnall from Northstream AB, Sweden, addresses the issues of packet-based roaming in 3G. The article analyzes the pros and cons of the connection to the home portal via the GGSN of home network and visited networks in GPRS and IMS roaming. It also discusses the issues of roaming between 2G and 3G systems from the service grade continuity and pricing points of view. As the number of mobile terminals with Internet access capability increases, concern about the shortage in number of IPv4 addresses emerges. Next-generation Internet, IPv6, has already been standardized for this critical issue. However, it will take some years for its global deployment. The fifth article, "Providing Scalable and Deployable Addressing in Third-Generation Cellular Networks," by Björn Landfeldt, Sanchai Rattananon, and Aruna Seneviratne from the University of Sydney and the University of New South Wales, Australia, proposes a method of translating IPv4 addresses between two different address realms. This article compares the existing methods from the viewpoint of scalability, public Internet initiation communication, and friendliness to application services. To be superior in these three criteria, this article proposes a new method, REBEKAH-IP (Realm-Based Kluge Address Heuristic IP), which combines Realm Specific IP (RSIP) and bidirectional NATs (Network Address Translators) with extensions to address allocation mechanisms.

The IP traffic increase will also require the optimization of 3G network architecture. The sixth article, "Key Concepts for Evolution toward Beyond 3G Networks," by Sami Uskela from Nokia, Finland, describes a 3G network evolution scenario to carry IP traffic as efficiently as possible. This article proposes to reallocate radio interface related processing into base stations in the radio access network (RAN). User plane handling is done by the RAN gateway. The networkwide radio resource management will be done by a new element, a common radio resource manager, while the remaining functionality is handled by the RAN access server (RNAS). It proposes also the separation of the user and control planes in the CN. Furthermore, it tries to streamline the evolved RAN and CN. The special issue is concluded by the final article, "Always Best Connected," by Eva Gustafsson and Annika Jonsson from Ericsson, Sweden, in which the authors propose an always best connected concept that allows personal connectivity to applications using devices and access technologies suited to his or her needs. This concept combines the features of access technologies such as ADSL, Bluetooth, and WLAN with cellular systems to provide an enhanced user experience for 2.5G, 3G, and beyond. This describes key technical issues for the ABC concept such as access discovery/selection, authentication, authorization, and accounting) support, mobility management, profile handling, and content adaptation.

Finally, as the guest editors of this special issue, we hope readers find it interesting and consider it a useful guide to research and development activities toward the implementation of 3G and beyond systems and wireless IP. We would like to thank all authors and reviewers who made this special issue a unique edition of novel activities in this field.

Biographies

Abbas Jamalipour [S '86, M '91, SM '00] (a.jamalipour@ieee.org) is with the School of Electrical and Information Engineering at the University of Sydney, Australia, where he is responsible for teaching and research in wireless data communication networks, mobility, traffic, and QoS management in wireless IP networks, and satellite systems. He holds a Ph.D. degree in electrical engineering from Nagoya University, Japan. He is the author of the book *The Wireless Mobile Internet — Architectures, Protocols and Services* (Wiley, 2003); the author of the first technical book written about the networking aspects of LEO satellites, *Low Earth Orbital Satellites for Personal Communication Networks* (Artech House, 1998); the author of a chapter in the prestigious *Wiley Encyclopedia of Telecommunications and Signal Processing* (John Proakis, Ed., 2003); and the author of a chapter in *Next Generation Wireless Networks* (Sirin Tekinay, Ed., Kluwer, 2001). He has authored over 80 papers in major journals and international conferences, and given numerous short courses and tutorials in major international conferences on 3G cellular and wireless IP networks. He has served on several major conferences' technical program committees, and organized and chaired many technical sessions and panels at international conferences including a symposium in IEEE GLOBECOM 2001. He is Vice Chair of the Satellite and Space Communications Technical Committee and the Asia Pacific Board, Coordinating Committee Chapter, IEEE ComSoc. He has organized several special issues on the topic of 3G and beyond systems as well as broadband wireless networks in IEEE magazines and journals. He is a technical editor of *IEEE Wireless Communications*.

Masami Yabusaki (yabusaki@netlab.nttdocomo.co.jp) is an executive research engineer in the Network Laboratories at NTT DoCoMo, Inc. He received B.S. M.S., and Ph.D. degrees in electrical engineering from Waseda University in 1982, 1984, and 1993, respectively. He joined Nippon Telegraph and Telephone Corporation (NTT) in 1984. He was engaged in research on an onboard baseband switch for an SS-TDMA system, 1984–1987; development of switch hardware and software for personal digital cellular (PDC) system, 1988–1991; and development and standardization of the 3G mobile network, IMT-2000, 1992–1999. He has served as a rapporteur of ITU-T SG11 on IMT-2000 radio access signaling and as a vice-chairman of 3GPP TSG-CN on GSM evolved IMT-2000 CN. He was CEO of DoCoMo Europe S.A., Paris, France, 1998–2000. He is serving as vice chairman of the mobile multimedia communications (MoMuC) committee in the Institute of Electronics, Information, and Communications Engineers (IEICE), Japan. He is currently responsible for leading all-IP network research and development.