Issues on Radio Access Technologies for the Fourth-Generation Mobile Communication System

Jin Young Kim

School of Electronics Engineering
Kwangwoon University
447-1, Wolgye-dong, Nowon-gu
Seoul 139-701, Korea

ABSTRACT

Emergence of the fourth generation mobile communication system (*4G system*) is now in its dawn. This paper proposes a perspective framework on the 4G system, and discusses system aspects of radio access technologies. The focus of the paper is to define the scope and features of the 4G system in an overall system/network viewpoint. From the foreseeable development trends, it is highly expected that whatever emerges in the 4G system will be some kind of constantly evolving and grand recursive concatenation of all the existing system/network developments.

I. INTRODUCTION

The rapid growth of wireless networks and services, accelarated by the third-generation mobile communication system (in short, *3G system*) research, has ushered in the era of the fourth-generation mobile communication system. Wireless communication systems have evolved to the meet the ultimate goal, to allow 'anywhere, anytime, anything, by anyone' communication customized to a particular subscriber's preferences, location, and social behavior. To reach this goal, much effort is still underway.

Since ITU (International Telecommunication Union) has raised an issue on the 3G system called FPLMTS (Future Public Land Mobile Telecommunication Service), it took about two decades until the 3G standard was established. The FPLMTS was first discussed at WARC MOB-87 in 1987, and frequency bands for the FPLMTS was decided at WARC-92 in 1992. In 1996, the 3G system was renamed from FPLMTS to IMT-2000 by the ITU-R.

This research was supported in part by University Academic Basic Research of the Institute of Information Technology Assessment (IITA) of Korea under Grant 2001-037-3.

From 1997, the 3G standards have been primarily driven by two international standardization organizations – 3GPP (Global Partnership Project) and 3GPP2 [1, 2]. The 3GPP developed a standard based on WCDMA (wideband code division multiple access) and GSM-MAP, while the 3GPP2 established a standard based on IS-2000 and ANSI (American National Standards Institute) – 41 [3,4].

In order to accommodate new and advanced needs of the subscribers, a great many efforts on a new wireless system (hereafter, we call it *4G system*) are being made in many countries and organizations. The 4G system can be described as over-the-horizon system. Although, the new wireless system is currently called '*system beyond IMT-2000*,' the name is expected to be harmonized to the '4G system' in the near future. Since the research on the 4G system is in its very early stage, there are little results showing the perspective framework of 4G services and systems. As the 3G system was based on the 2G system, the 3G system will form a sound base for commercial take-off of the 4G system around 2010. The definition and identification of the 4G system entails new service features, new network types, new frequency bands, new air interfaces, and new terminals.

This paper aims to shed some light on the overall framework of the 4G systems through suggestion and envisioning of a variety of system/network aspects of the 4G system. A perspective framework of the 4G system is proposed in the context of radio access technologies. Conclusions will be drawn suggesting the upcoming challenging issues for implementation of the 4G system.

II. CONCEPT OF 4G SYSTEM

Since the start of discussion on "system beyond IMT-200" by ITU-R in 1999, the 4G system is primarily being triggered by a number of following factors:

i) Rapid growth of mobile systems and services,
ii) Exponential spread of the internet and intranet,
iii) Emergence of nomadic computing,

iv) Convergence of communications and broadcasting,
v) Deregulation and liberalization of telecommunications, and
vi) Openness and integration of different networks.

In Fig. 1, the service coverage of the 4G system is depicted with respect to the mobility and data rate. The radio access of the 4G system should support data rate up to a few hundred Mbps under various mobility environments, and entails a wide range of air interfaces. Each part of the radio access system should be flexible enough to adapt itself with high reconfigurability to the varying traffic load, channel environments, and service features. Aiming at faster and more efficient transmission of high-speed data, the following techniques should be defined in a new paradigm:

i) High spectrum/power efficiency (modulation/demodulation, adaptive modulation),
ii) High reliability (channel coding, adaptive coding),
iii) High system capacity (smart antenna, multiuser detection, diversity, power control, multiple access/duplex),
iv) High flexibility (software defined radio), and
v) High connectivity (handoff).

III. RADIO ACCESS TECHNOLOGIES

Realization of the 4G system demands new technologies in the wide areas of system components. We describe the promising key technologies for the 4G system in terms of radio access technologies. Towards the 4G system, many radio access technologies are now arising as promising solutions to enhance the spectrum efficiency and system capacity. In Table 1, the radio access technologies between the 2G, 3G, and 4G systems are summarized and compared among 2G, 3G, and 4G systems.

III. 3. 1. Smart Antenna

A smart antenna consists of many antenna elements whose signals are processed adaptively in order to exploit the spatial dimension of the mobile radio channel. An adaptive antenna array has potential to provide designers with an extra dimension of SDMA (space-division-multiple-access) along with FDMA (frequency division multiple access), TDMA (time division multiple access), and CDMA in solving the problems related with the realization of the 4G system. It is widely accepted that an adaptive antenna array will offer potential solutions to a number of the key requirements since it provides many promising features such as high capacity, high spectrum efficiency, and more degrees of freedom to adjust cell coverage characteristics, leading to more efficient use of radio resources. And, its particular configuration depends on the radio channel characteristics, terminal mobility, implementation complexity, capacity requirements, and environmental issues, etc. In the early commercial 3G system, the smart antenna may be not be adopted, however, it may be employed in the 3G evolution system.

III. 3. 2. Multiuser Detection

The CDMA system performance may be degraded when the MAI (multiple access interference) becomes strong. The MAI from high-power users can significantly corrupt the received signals of low-power users, which is known as '*near-far problem.*' To overcome the near-far problem and mitigate the MAI, concept of multiuser detection (MUD) (also called "*Interference Cancellation* (IC)") has been proposed. In spite of the superior performance of the optimum multiuser detector, its complexity is not acceptable in implementation of the system. The optimum multiuser detector is basically a maximum likelihood sequence detector consisting of a bank of matched filters followed by a Viterbi algorithm. To avoid prohibitive computational complexity of the optimum MUD, many suboptimal multiuser detectors have been proposed. The suboptimal detectors include decorrelating detector, multistage detector, neural-network based detector, successive interference cancellation (SIC) detector, parallel interference cancellation detector (PIC) detector, adaptive detector, and iterative detector, etc.

In the 4G system, the MUD is a very promising solution for improving receiver performance as well as system capacity and coverage in both uplink and downlink, while in the standardization of the 3G system, the MUD has not been actively discussed. In the uplink, interference estimation and subtraction based MUD appears to be the most promising one for practical implementation.

III. 3. 3. Software Defined Radio

So far, the mobile communications world has witnessed the parallel emergence of a wide variety of radio standards throughout the world. The recent activities of the 3G standard such as the 3GPP (global partnership project) and 3GPP2 have resulted in a growing interest in the field of multi-standard software defined radio (SDR). The SDR represents '*radio functionalities defined by software.*' The capability of processing a signal corresponding to a wide range of frequency bands and channel bandwidths in a cost-effective manner may also be a critical issue in the roadmap of the 4G system. The SDR provides a solution to this issue. The digital signal processing technology has led us to a point where it is feasible to change characteristics of a radio depending on the software loaded into it.

The SDR generalizes the primary functions of a radio system into a set of functional modules connected by information and control signals. It may have all the operating parameters defined in software rather than hardware, and would be extremely flexible with the following benefits in many commercial applications:

i) Fully programmable,
ii) Multimode terminal,
iii) Easily adaptable to new signal processing technique, and
iv) Easily expandable for new services

III. 3. 4. Channel Coding

There have been many channel coding schemes (such as RS code, BCH code, convolutional code, etc.) to improve performance of many kinds of systems by compensating channel distortion in wireless, optical, and magnetic channels. Recently, in the channel coding community, there has been a focus on turbo code (also termed *parallel concatenated convolutional code*) introduced in 1993. The substantial coding gain through turbo coding has been confirmed for a CDMA system in a wireless channel as

well as in an AWGN channel.

The turbo code is a kind of concatenated convolutional code, and performs decoding in an iterative manner. The encoder is formed by concatenating two constituent codes in parallel and by separating the codes by the interleaver. This interleaver permutes the information sequence and then uses this as the input to the second component encoder.

In the 2G systems, the convolutional code was primarily selected as the channel coding scheme, while in the 3G system, the convolutional and turbo codes have been alternatively employed for low and high rate data transmissions. In the 4G system, this kind of trend in the 3G system is expected to continue, however, the use of coded modulation and adaptive coding schemes may be challenging issues to improve spectrum efficiency and to adapt to changing channel conditions, respectively. In addition, for service applications which can tolerate delay, ARQ (automatic repeat request) can be applied for the error control in the MAC (medium access control) layer.

III. 3. 5. Tx/Rx Diversity

Diversity is a preventive way to mitigate fading effect, whereas power control combats against fading by controlling the transmit power. The diversity is useful in a full range of mobile speeds, and can reduce power rise effect. The diversity also requires smaller transmit power which results in capacity increase and less power consumption (which is important to the multimedia terminal). Up to now, many kinds of diversity combining techniques have been used independently or in a combined way, and they fall into the following categories: space, frequency, time, and polarization. The diversity schemes include path diversity, receive antenna diversity, transmit diversity, and macro diversity.

So far, a number of transmit diversity techniques have been proposed for the downlink. It has been recognized that transmit diversity on the downlink can provide a means to achieve similar diversity gain as for the receiver diversity without complexity of extra receiver. In the 3G cdma2000 system, multicarrier transmit diversity has been proposed on its downlink configuration. The major transmit diversity includes orthogonal transmit diversity, time switch transmit diversity, and selection diversity. In the 4G system, these kinds of transmit diversity will be surely considered for enhancement of the downlink performance.

III. 3. 6. Modulation/Demodulation

In the 4G system, a high rate data up to a few hundred Mbps in a static user should be supported for transmissions of speech, fax, data, video, etc. These trends have motivated extensive research on modulation techniques with high spectral efficiency and efficient radio transmission techniques. One of the approaches is multicarrier transmission technique. In the multicarrier transmission technique, input data stream is divided into many substreams, each of which has a much lower bit rate. These substreams are modulated onto many subcarriers. The first system using multicarrier modulation was military HF (high frequency) radio links in the late 1950s and early 1960s. OFDM (orthogonal frequency division multiplexing) patented in the U.S.A. in 1970 is a special form of multicarrier modulation, and has densely spaced subcarriers with overlapping spectra of the modulating signal.

In the 2G and 3G systems, the QPSK (phase shift keying) and GMSK series have been mainly employed as modulation formats. However, in the 4G system, QAM (quadrature amplitude modulation) may be a strong candidate due to its high spectral efficiency as well as MPSK (M-ary PSK) series. The variable QAM and M-ary PSK can be alternatively selected according to the traffic and channel conditions.

With the projected demand for multimedia services, the ability to provide spectrally efficient and flexible data rate access is one of the important design considerations of the 4G systems. One of the approaches to satisfy both of these requirements is to adapt the modulation and transmission power according to the instantaneous propagation conditions. This technique is called *adaptive modulation* which has been employed in many systems such as V.34 modem and two-way cable modem. The adaptive modulation can effectively improve BER (bit error rate) performance on radio channels which suffer from fading and shadowing.

III. 3. 7. Power Control

Power control is essential for the CDMA-based systems to keep the transmit power at a minimum level while satisfying the required QoS, and for maximizing the system performance by reducing unnecessary interference, and also lengthening the battery life. Typically, three types of power controls have been devised to combat near-far problem (path loss), shadowing, and fading: open-loop, closed-loop, and outer-loop power controls. Most of recent studies have focused on making power control faster and more accurate, and especially how to accommodate multi-rate and multi-QoS services. And, the closed-loop power control based on signal-to-interference ratio (SIR) attracts much interest even in downlink, and one more interesting issue is distributed power control as well as centralized control. It should be noted that the power control (particularly, closed-loop power control) targets low-to-moderate mobile speeds, and has a so-called *power-rise problem.*

To mitigate these shortcomings, diversity is widely used in the current and upcoming systems. In a wide sense, gating and DTX (discontinuous transmission) can be seen as another way of power control. In the 2G/3G system, the step size and frequency of power control are fixed once the propagation channel is identified, however, in the 4G system, they can be varied according to the channel propagation environments through enhanced channel estimation. This kind of technique is typically called *adaptive power control*, and is a promising approach for the 4G system implementation.

III. 3. 8. Handoff

In a mobile cellular system, handoff is performed for link quality maintenance and for reducing interference in the system. For seamless networking of multiple interworking systems, the

handoff will be a very essential part of the 4G system. In the 2G and 3G system, the intra-network handoff is the main stream based on physical layer characteristics such as signal strength, BER, range, etc. However, in the 4G system, inter-network (inter-system) handoff may be a critical issue as well as the intra-network handoff. The handoff of the 4G system may demand the following features:

i) Based on QoS and cost,
ii) Based on available spectrum,
iii) Dependent on higher (application) layer, and
iv) Dependent on different network legacies.

III. 3. 9. Multiple Access and Duplex

In the 2G systems, the TDMA and the CDMA have become primary multiple access techniques in the GSM and the IS –95 systems, respectively. However, in the 3G systems, the CDMA has been widely adopted due to its many advantageous features compared to the TDMA. In the 4G system, it is highly expected that the trend of the 3G system be maintained. However, the TDMA system can be a strong alternative in some applications such as the OFDM-based transmission environment, TDD (time division duplex) mode operation in a hot-spot cell, etc.

Unlike voice-only communications, in the 4G system, main service will be various kinds of multimedia applications in which the system capacity is limited by the downlink traffic. To cope with the problems caused by traffic imbalance between uplink and downlink, the TDD can be a solution in that it permits one to allocate the resource more flexibly compared to the FDD (frequency division duplex). One interesting feature of the TDD is that for a period of time, the channel impulse response is identical for the forward and reverse links resulting in channel reciprocity. And, the multimedia service is controlled by the number of allocated time slots. The TDD systems are generally used for low-mobility applications such as indoor, picocell environments because the correlation between the forward and reverse links degrades as the fading rate becomes higher.

IV. CONCLUSIONS

The concepts and ideas in this paper have just scratched the surface of the potentialities for the 4G system. We have a significant amount of future work ahead of us in more granular levels of all the aspects for implementation of the 4G system. A number of challenging issues listed below should be solved:

i) Development of innovative air interfaces,
ii) Channel modeling and measurements above 2GHz band for decision of operating bands,
iii) Deployment of layered network architecture,
iv) Development of multimode reconfigurable terminal/appliances,
v) Management and integration of different networks/systems, and
vi) Generation of new services (business models).

We are now entering a new era in the development and evolution of the 4G systems which should meet the demanding requirements of a customer-based global market place. We also would like to point out that the 4G market opportunities demand substantial technological innovation for the adequate provisioning of personal/service mobility, ubiquitous coverage, robust communications, and high-capacity systems.

With recent breakthroughs in component and system technologies as well as network and service technologies, the ubiquitous communication with anyone in anytime, anywhere through 4G system will surely be a reality. In the era of the 4G systems, as witnessed in the 3G system, the different world regions need to cooperate particularly in the field of standardization, regulation, and spectrum allocation to ensure widespread availability of the advanced and affordable wireless services and applications. The national and regional borders should be more often transcended, and interconnection of the networks and interoperability of services should be highly encouraged with the objective of enhancement of quality of life in the ever-maturing information age.

REFERENCE

[1] TIA cdma2000, "Wideband cdmaOne radio transmission technology proposal," *ITU-R, Study Groups*, June 2000.
[2] 3GPP web site; www.3gpp.org
[3] T. Ojanpera and R. Prasad, *Wideband CDMA for Third Generation Mobile Communications*, Artech House, 1998.
[4] Holma and Toskala, *WCDMA for UMTS*, Wiley, 2000.

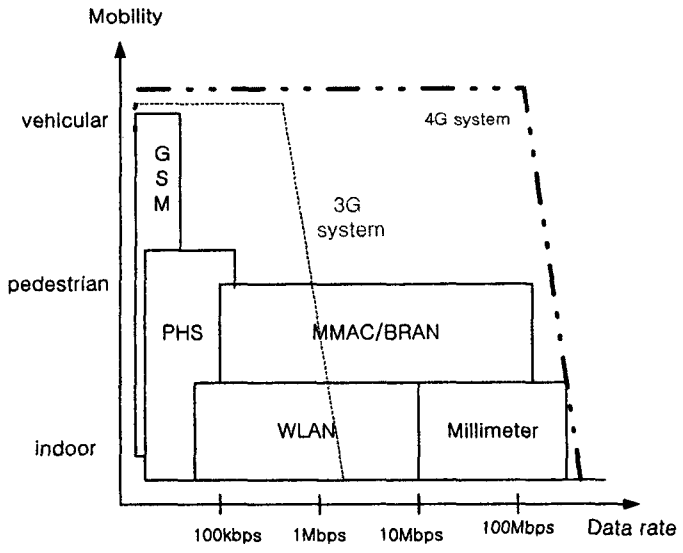

Fig. 1. Service coverage of 4G system.