Trends in LTE/WiMAX Systems

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In Japan, the total number of mobile-phone and personal handy-phone system (PHS) users reached 111 million as of the end of February 2009 and the penetration rate of the third-generation mobile communications system (IMT-2000) exceeded 88%. These figures testify to the provision of a data communications environment for mobile users. At the same time, the use of data communications via mobile phones, mainly Internet connections and video transmission, is growing as social and economic activities become increasingly advanced and diversified. As a result of these trends, there is eager anticipation for the introduction of mobile communications systems that surpass existing ones in speed, capacity, and convenience. In this paper, we describe the current state of Long Term Evolution (LTE) and Worldwide Interoperability for Microwave Access (WiMAX) for achieving high-speed mobile wireless access services, discuss trends for bit-rate enhancement, and describe the future outlook for these systems. We also outline the technologies used for these systems.

1. Introduction

Since the launch of third-generation (3G) mobile communications services, high-speed wireless access services that provide high-speed data transmission in a mobile environment have come to be used in diverse applications including E-mail and Web access using a mobile phone. Transmission bit rates of 7.2 Mb/s have recently been achieved in cellular systems, and Worldwide Interoperability for Microwave Access (WiMAX) services, which aim for even higher bit rates, have been launched.

In this paper, we describe the current state of the Long Term Evolution (LTE) and WiMAX systems for achieving high-speed mobile wireless access services, discuss trends toward future bit-rate enhancements, describe the future outlook for these systems, and outline the technologies used in these systems.

2. LTE/WiMAX trends and future outlook

Trends of mobile phone systems and broadband mobile wireless access systems are shown in **Figure 1**. Wireless systems for achieving high-speed mobile wireless access services can be divided into two groups. The first consists of cellular systems (International Mobile Telecommunications-2000 [IMT-2000]). These include Wideband Code Division Multiple Access (W-CDMA), High-Speed Downlink Packet Access (HSDPA), High-Speed Uplink Packet Access (HSUPA), High-Speed Packet Access Plus (HSPA+), and LTE/LTE-Advanced specified by the 3rd Generation Partnership Project (3GPP) and CDMA2000 1x and Ultra Mobile Broadband (UMB) specified by 3GPP2. The second group consists of extensions of fixed wireless access systems to incorporate mobile functions. These include WiMAX (IEEE 802.16e) and its

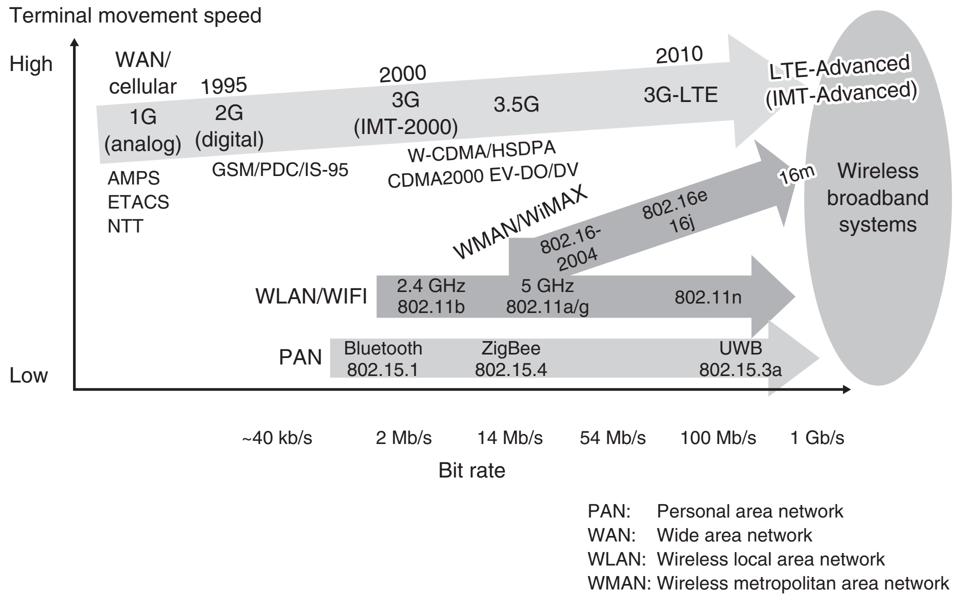

Figure 1
Trends of mobile communications systems.

extended system, IEEE 802.16m, specified by the IEEE 802.16 committee.

The systems that have been deployed so far for providing high-speed mobile wireless access services are High-Speed Packet Access (HSPA) (which covers W-CDMA, HSDPA, and HSUPA) and IEEE 802.16e. In Japan, HSPA-based services featuring 1.4 Mb/s in the uplink and 7.2 Mb/s in the downlink were launched in November 2008 and IEEE 802.16e-based services were launched in February 2009. Although uplink/downlink data rates for WiMAX (IEEE 802.16e) have not yet been announced, standards indicate that 4 Mb/s in the uplink (16-state quadrature amplitude modulation [16QAM], R = 3/4, 12 user symbols) and 45 Mb/s in the downlink (64QAM R = 5/6, 32 user symbols when using the multiple-input multiple-output [MIMO] scheme) can be achieved.

The number of mobile-phone and personal handy-phone system (PHS) users in Japan stood at 111 million as of the end of February 2009, while the penetration rate of the 3G mobile communications system (IMT-2000) came to more than 88%. These figures reflect the provision of a data communications environment for mobile users. Furthermore, against the background of advanced and diversified social and economic activities, the use of data communications via mobile phones such as for Internet connections and video transmissions shows an upward trend, and there is much anticipation for mobile communications systems with even higher bit rates, greater capacities, and higher levels of convenience. With the above in mind, Japan's Ministry of Internal Affairs and Communications (MIC) has directed studies on technical requirements toward the introduction of a 3.9G mobile communications system as an enhancement of the 3G mobile communications system (IMT-2000). This enhanced system is scheduled for commercialization in Japan sometime in 2010. A partial report[1)] on this system was received by MIC in December 2008. It presented the following five themes as a conceptual foundation for the 3.9G mobile communications system (3G-LTE).

1) Efficient spectrum use
2) Flexible networks
3) Affinity with users

4) Advanced wireless access
5) Global scope

The basic requirements of the 3.9G mobile communications system based on these themes are listed in **Table 1**. Usage scenarios for the 3.9G mobile communications system will, of course, include commonly envisioned next-generation services like high-definition image transmission and video delivery, but in addition, we can expect download times for today's popular applications (such as E-mail communication, Web access, and music downloading) to be shortened and their ease of use to be improved dramatically.

As for the future of LTE/WiMAX systems, standardization activities toward the next-generation mobile communications system after the 3.9G system (4G system) have already begun at 3GPP and in the IEEE 802.16 committee. Moreover, work on proposals for the "IMT-Advanced" system under the direction of the International Telecommunication Union Radio Communication Sector (ITU-R) is now proceeding at a frenzied pace. The cutoff for system proposals is October 2009.

In the following sections, we outline the technologies that will support the 3.9G and 4G mobile communications systems.

Table 1
Basic requirements of 3.9G mobile communications system.[1)]

Maximum bit rate	Downlink: 100 Mb/s or greater Uplink: 50 Mb/s or greater
Spectrum usage efficiency	≥3 (downlink), ≥2 (uplink) times 3.5G (HSPA release 6)
Occupied bandwidth	Scalable bandwidth
Network	All-IP network
Extendibility to future systems	Smooth extendibility to 4G mobile communications system
Transmission quality	Shorter delay than current 3.5G
Global scope	International roaming and interoperability

3. Technology overview of LTE systems

With the standardization of LTE completed in December 2008, 3GPP is now working to complete standardization of LTE-Advanced by the end of 2010 as an extension of LTE to satisfy IMT-Advanced requirements while maintaining backward compatibility with LTE. The performance requirements of HSPA, LTE, and LTE-Advanced are listed in **Table 2**.[2),3)] The key technologies being applied to LTE and those currently being discussed for LTE-Advanced in 3GPP are outlined below.

3.1 Key technologies of LTE

1) Efficient multiple access technology

In the downlink, LTE uses orthogonal frequency division multiple access (OFDMA), which provides good performance in frequency selective fading channels and enables flexible radio resource allocation. In the uplink, in contrast, LTE uses single-carrier frequency division multiple access (FDMA), whose transmit signal retains a small peak-to-average power ratio. This makes for good power conversion

Table 2
Main requirements of HSPA, LTE, and LTE-Advanced.

	HSPA		LTE		LTE-Advanced	
	Downlink	Uplink	Downlink	Uplink	Downlink	Uplink
Peak spectrum usage efficiency (b/s/Hz)	3	2	>5	>2.5	30	15
Average spectrum usage efficiency (b/s/Hz/cell)	0.53	0.33	1.6–2.1	0.66–1.0	2.4–3.7	1.2–2.0
Cell-edge spectrum usage efficiency (b/s/Hz/user)	0.02	0.01	0.04–0.06	0.02–0.03	0.07–0.12	0.04–0.07
Operating bandwidth (MHz)	5		1.4–2.0		up to 100	
User plane delay (unidirectional) (ms)	25		<5		<5	
Connection setup delay (ms)	—		<100		<50	

efficiency in the power amplifier thereby lowering device power consumption.

2) Multi-antenna techniques

LTE supports MIMO operation by using multiple antennas in both the base station and terminals to improve spectrum usage efficiency and/or increase coverage. Suitable operation modes among spatial multiplexing, pre-coding, and transmit diversity can be selected according to the propagation environment. For spatial multiplexing in the downlink, LTE supports single-user MIMO (SU-MIMO) with up to four streams of transmission as well as multi-user MIMO (MU-MIMO) where the base station is sending different data streams to different users using the same frequency resource. For uplink spatial multiplexing, only MU-MIMO operation is supported in the first release of LTE.

3) Scalable bandwidth support

The LTE solution enables spectrum flexibility where the transmission bandwidth can be selected between 1.4 and 20 MHz depending on the available spectrum.

4) Latency reduction

The user plane latency in LTE can be as low as 10–20 ms. This low latency is relevant for improving end user performance since many applications such as online gaming and other interactive applications benefit from low latency. It is enabled by a short sub-frame size of 1 ms, which is half that of HSDPA, and the use of a simplified network architecture. The simplified radio-resource control protocol in LTE enables the control plane latency and interruption time in a handover process to be reduced.

5) Simplified protocol architecture

LTE is purely a packet switched only system without a specific circuit switched domain and supports voice over Internet protocol (VoIP).

6) Simplified network architecture

LTE has a flat architecture in which the wireless access network is configured with only base stations, thereby reducing the number of inter-node interfaces and reducing network construction costs.

3.2 Key technologies of LTE-Advanced

1) Carrier aggregation

LTE-Advanced will support the aggregation of multiple carriers, which allows higher data rate transmission by using multiple frequency blocks (component carriers), each with a maximum bandwidth of 20 MHz having backward compatibility with LTE.

2) Multi-carrier transmission support in uplink

Within a component carrier, LTE-Advanced will support multi-carrier transmission through clustered discrete Fourier transform spread OFDM (DFT-S-OFDM). Combining this with the carrier aggregation technique improves user throughput and capacity in the uplink through flexible radio resource allocation.

3) Extension of MIMO technology

LTE-Advanced will support SU-MIMO with up to eight streams in the downlink and up to four streams in the uplink, thereby improving user throughput and peak spectrum usage efficiency.

4) Coordinated multiple point transmission/reception technology

LTE-Advanced will support coordinated multiple point transmission (coordinated scheduling/beamforming and joint transmission) in the downlink and coordinated multiple point reception in the uplink which can improve cell-edge user throughput.

5) Relaying support

LTE-Advanced will support the introduction of relay stations in order to improve cell coverage and/or user throughput performance with low deployment cost.

4. Technology overview of WiMAX systems

The IEEE 802.16 committee is developing the IEEE 802.16m[4),5)] standard toward the 4G mobile communications system. The IEEE 802.16m standard is based on WiMAX

(IEEE 802.16e), and its basic technologies follow WiMAX technologies,[6),7)] as described below.

1) OFDMA is applied in both the uplink and downlink.
2) Both time division multiple access (TDMA) and FDMA are supported for both the uplink and downlink.
3) MIMO technology is introduced to improve system performance.
4) IP-based protocol architecture is adopted.

Based on the above technologies, IEEE 802.16m will introduce new technologies with the aim of achieving even higher speeds and greater broadband performance and satisfying the requirements of IMT-Advanced. Several of the key technologies from among these are described below.

4.1 Extension of MIMO technology

While WiMAX (IEEE 802.16e) has supported the use of up to two antennas on both the transmit and receive sides, the use of up to eight antennas for both transmitting and receiving is being considered for IEEE 802.16m to improve throughput. Furthermore, in addition to supporting SU-MIMO, which transmits multiple data streams from multiple antennas to one user, studies are being conducted on the use of MU-MIMO to transmit multiple data streams to multiple users and accommodate more mobile terminals and the use of Multi-BS MIMO, which uses the antennas of different base stations to improve throughput at the cell edge.

4.2 Multi-carrier support

It has been decided that the maximum bandwidth of the radio carrier supporting the physical (PHY) layer of IEEE 802.16m will be 20 MHz to facilitate the use of WiMAX (IEEE 802.16e) technologies. Here, however, a significant improvement in throughput cannot be expected. For this reason, IEEE 802.16m will use multi-carrier technology that bundles together multiple PHY layers (radio carriers) that appear to upper layers as one fat transmission channel. As shown in **Figure 2**, this bundling of carriers will be supported on the media access control (MAC) layer. Theoretically, multi-carrier technology can provide an upper layer with a throughput corresponding to the number of bundled carriers.

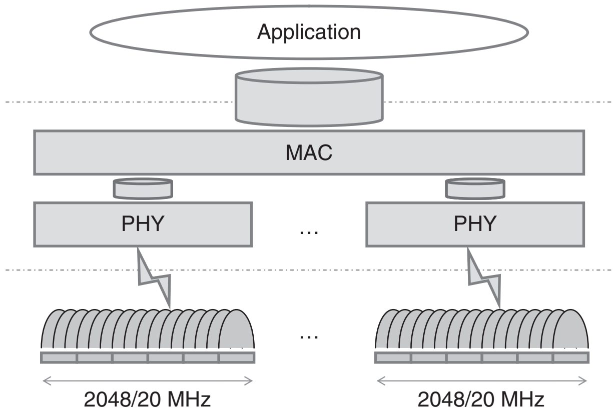

Figure 2
Multi-carrier support.

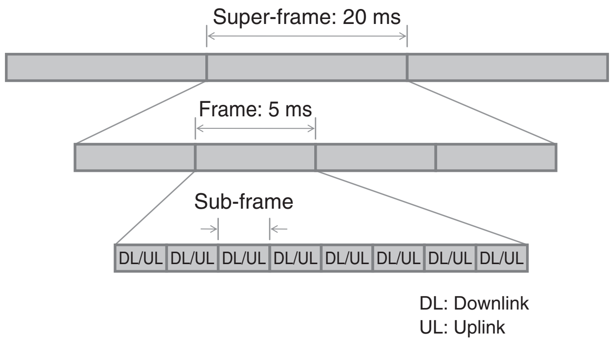

Figure 3
802.16m frame structure.

4.3 Hierarchical frame structure

In IEEE 802.16m, the WiMAX (IEEE 802.16e) radio frame structure is being extended to include a super-frame and sub-frames, as shown in **Figure 3**. The idea behind the use of a super-frame is to improve spectrum usage efficiency by identifying control signals that do not have to be transmitted every frame and transmitting

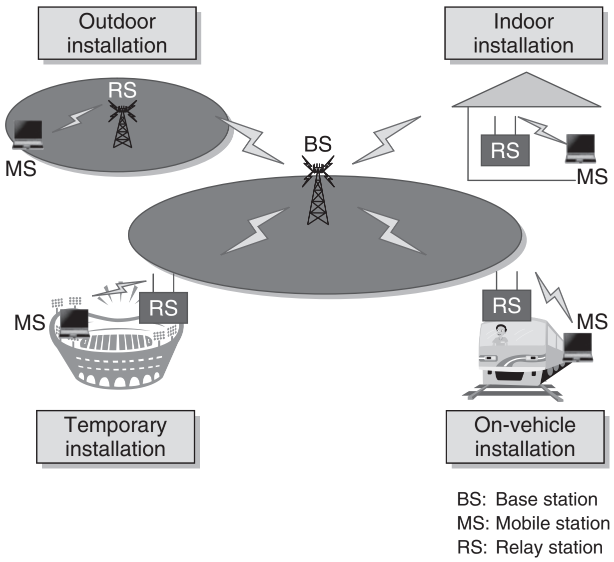

Figure 4
Multihop relay usage scenarios.

them every super-frame. The introduction of sub-frames, meanwhile, can reduce transmission delay in the wireless section. Switching between the uplink and downlink when using TDMA will be performed every sub-frame.

4.4 Multihop relay support

The downside of increasing the bit rate of a wireless communications system is an increase in power consumption. As a result, there is no other choice but to reduce the size of the service area covered by one radio base station in comparison with existing systems. Moreover, signal strength indoors is low due to building penetration loss, which nullifies the much promoted high-speed features. To overcome these problems, IEEE 802.16m introduces relay stations in addition to the use of base stations and mobile stations just like in LTE-Advanced, thereby enabling the support of a multihop relay system that can expand the service area and improve throughput indoors. Typical multihop usage scenarios are shown in **Figure 4**.

For the existing WiMAX (IEEE 802.16e), IEEE 802.16j[8),9)] is defined as a multihop relay standard. However, work on the IEEE 802.16j standard began after work on the IEEE 802.16e standard was completed. As a result, it has a somewhat complicated configuration to maintain compatibility. On the other hand, for IEEE 802.16m, both the basic system standard and its multihop-relay standard are being studied at the same time, which bodes well for an optimal and simple configuration.

4.5 Femtocell support

The femtocell is another candidate technology for expanding the service area and improving throughput indoors. A femtocell is a mobile communication system for a small area such as the home or SOHO. In a femto cell, a compact base station is connected to the mobile operator's network via an Internet connection such as an asymmetric digital subscriber line (ADSL) or fiber to the home (FTTH). The IEEE 802.16m standard is targeting an ultimate model whereby end users purchase compact base stations at retail electronics stores and install them by themselves. This ultimate model, however, prevents base stations from being set up in a systematic manner as has normally been done by mobile operators, and finding ways to mitigate interference here is a major challenge. In addition, the femtocell uses the Internet as an access line between the compact base station and mobile operator's network, which means that security, band compensation, absorption of time delays, and so on will also be problems that need to be addressed. To overcome these problems, the concept of a self-organizing network (SON) is being studied. In SON, plug & play technology will be applied to compact base stations to achieve self-configuration and self-optimization in conjunction with the core network, as shown in **Figure 5**.

5. Conclusion

This paper described current trends in the LTE and WiMAX systems for achieving high-speed mobile wireless access services and outlined

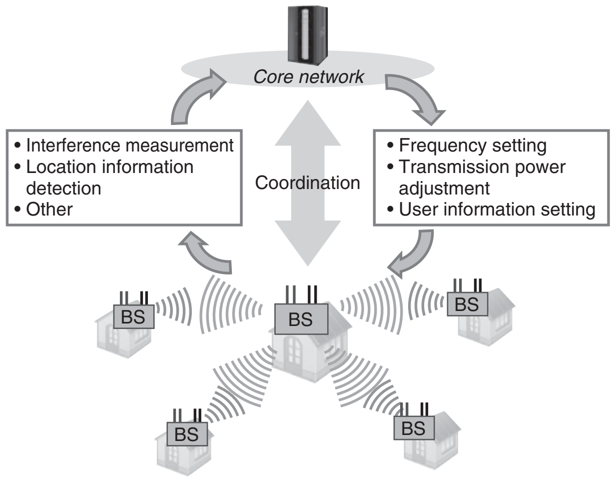

Figure 5
Concept of self-organization network.

the technologies supporting these systems. On the basis of these trends, Fujitsu plans to link up with overseas R&D bases and take a global approach to researching and developing major access platform technologies for both fixed and mobile-wireless systems.

References

1) For Introduction of 3.9-Generation Mobile Communications System, Partial Report from the Telecommunications Council.
http://www.soumu.go.jp/main_sosiki/joho_tsusin/eng/Releases/Telecommunications/news081211_3.html
(in Japanese).
http://www.soumu.go.jp/s-news/2008/081211_3.html
2) 3GPP: TR25.913 V8.0.0 Requirements for Evolved UTRA (E-UTRA) and Evolved UTRAN (E-UTRAN) (Release 8).
http://www.3gpp.org/ftp/Specs/2008-12/Rel-8/25_series/
3) 3GPP: TR36.913 V8.0.0 Requirements for Further Advancements for E-UTRA (LTE-Advanced) (Release 8).
4) IEEE 802.16m System Description Document (SDD) [Draft].
http://wirelessman.org/tgm/index.html
5) IEEE 802.16m Amendment Working Document (AWD).
http://wirelessman.org/tgm/index.html
6) T. Saito et al.: Fujitsu's Challenge for Mobile WiMAX. *FUJITSU*, Vol. 60, No. 1, pp. 2–9 (2009). (in Japanese).
7) Air Interface for Fixed and Mobile Broadband Wireless Access Systems. IEEE STD 802.16-2005, February 2006.
8) IEEE 802.16: IEEE Std 802.16j.
http://www.ieee802.org/16/pubs/80216j.html
9) M. Okuda et al.: Multihop Relay Extension for WiMAX Networks—Overview and Benefits of IEEE 802.16j Standard. *FUJITSU Sci. Tech. J.*, Vol. 44, No. 3, pp. 292–302 (2008).

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