Fujitsu's Challenges for WiMAX System-on-a-Chip Solutions

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Worldwide Interoperability for Microwave Access (WiMAX) is a promising candidate for providing high-data-rate mobile broadband access systems around the world. This paper describes specific features of Mobile WiMAX, such as scalable orthogonal frequency division multiple access (OFDMA), adaptive modulation and coding, and smart antenna technologies, a system configuration, candidate applications, and our challenges for WiMAX system-on-a-chip (SoC) solutions.

1. Introduction

In recent few years, the number of mobile Internet access users has been increasing very rapidly and requirements for high-data-rate mobile broadband access systems are also increasing. Worldwide Interoperability for Microwave Access (WiMAX) is a promising candidate for high-speed mobile broadband access. There are two flavors of standards for WiMAX: IEEE 802.16-2004[1] and IEEE 802.16e-2005.[2] IEEE 802.16-2004 is mainly focused on fixed wireless access technologies while IEEE 802.16e-2005 is an amended version of IEEE 802.16-2004 that adds features and attributes to support mobility. In the IEEE 802.16e-2005 standard, there are a lot of parameters related to the media access control (MAC) protocol and physical (PHY) layers. Therefore, to keep interoperability among devices, an industry consortium called the WiMAX Forum develops guidelines known as system profiles, which specify the frequency band, PHY parameters, and MAC parameters to be used. We have already released commercial products such as MS baseband SoC,[3] MS RF module[4] and base stations[5),6] for Mobile WiMAX (MS: mobile station, SoC: system-on-a-chip, RF: radio frequency).

This paper summarizes Mobile WiMAX's specific PHY features, a WiMAX system configuration, candidate applications for the system, and our challenges for Mobile WiMAX SoC solutions.

2. Mobile WiMAX specific PHY features

Here, we describe some PHY features that are specific to Mobile WiMAX.

2.1 Scalable OFDMA

Mobile WiMAX uses a scalable orthogonal frequency division multiple access (OFDMA) technology. A comparison between Fixed WiMAX and Mobile WiMAX is shown in **Figure 1**. For Fixed WiMAX, the size of the fast Fourier transform (FFT) is fixed to 2048 points. If the signal bandwidth changes, the sub-carrier frequency spacing changes too. This means that if the system changes the service bandwidth from 20 MHz to 10 MHz in a mobile environment, the Doppler effects will change because there are different Doppler effects for the 20- and 10-MHz bandwidths. To achieve the same performance

for the systems, the channel estimation function should be changed according to the bandwidth, but this increases the circuit complexity. The scalable OFDMA technology used in Mobile WiMAX avoids this phenomenon. The scalability is provided by adjusting the FFT size while fixing the sub-carrier spacing at 10.94 kHz. Since the sub-carrier spacing is fixed, the impact of the Doppler effect is the same for systems using different bandwidths. This approach enables one particular channel estimation method to be applied to the entire range of environments.

2.2 Adaptive modulation and coding

To enhance the coverage and capacity of mobile applications, Mobile WiMAX uses an adaptive modulation and coding (AMC) function in the system. Mobile WiMAX supports quadrature phase shift keying (QPSK), 16 quadrature amplitude modulation (16QAM), and 64QAM as mandatory in the downlink and supports QPSK and 16QAM as mandatory in the uplink. In addition, the system supports both convolutional coding (CC) and convolutional turbo coding (CTC) with variable coding rate and repetition coding. AMC can use various combinations from these modulation schemes and coding schemes to achieve a high data rate, as shown in **Table 1**.

2.3 Smart antenna technologies

To enhance system performance, Mobile WiMAX uses smart antenna technologies that include beamforming, space-time coding (STC), and spatial multiplexing (SM). For beamforming, the system uses multiple antennas to transmit weighted signals to increase the system's coverage and capacity. This enables a base station (BS) to get a feedback signal from an MS; then, the BS calculates the weight for each signal. The STC is a transmit diversity technology[7] and the scheme uses two transmit antennas and one receive antenna. The STC provides a spatial diversity gain in the system and this technique reduces the fading margin. The SM[8] achieves higher peak rates and increases the data throughput in a link. With SM, multiple data streams are transmitted from multiple antennas. If two transmit antennas and two receive antennas are used, the increase in data transmission rate is twice that in the best condition before.

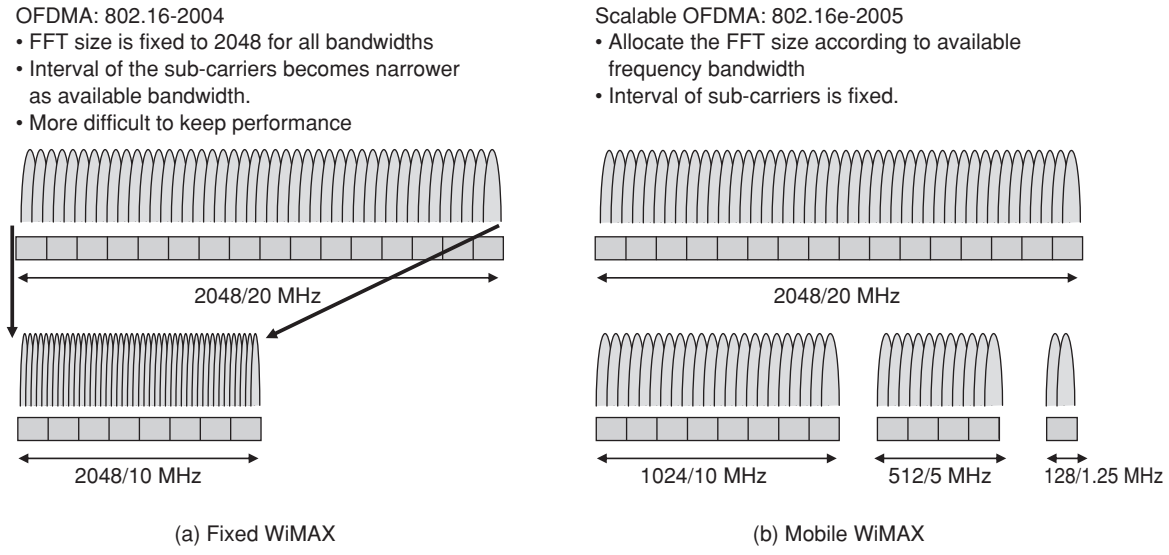


Figure 1
Comparison between Fixed WiMAX and Mobile WiMAX.

3. Mobile WiMAX system configuration

A next-generation packet-based network configuration is shown in **Figure 2**. 3G/3.5G, LTE and WiFi/WiMAX systems are connected to an all-IP-based network (IP: Internet protocol). As described before, WiMAX has very flexible functions for achieving a variety of services. To support these features effectively, the all-IP core network should be flexible to handle their functions. Thus, the core network should satisfy the following requirements:[9)]

- Functionality to cope with the demand for continuous broadband service
- Ease of use and ease of service provision
  To achieve new services provided through convergence, such as fixed-mobile convergence (FMC)
  To deal with the issues of quality, security, and robustness
  To achieve autonomic control and self-organization

To satisfy these requirements, the Next Generation Network (NGN) is a promising candidate for the all-IP core network.

4. Candidate applications for Mobile WiMAX

This section describes some candidate applications for Mobile WiMAX. Mobile WiMAX provides a high-data-rate service in the mobile environment at a low cost. Some service models

Table 1
Mobile WiMAX PHY data rates with partial usage of sub-channels.

Parameter		DL	UL	DL	UL
System bandwidth (MHz)		5		10	
FFT size		512		1024	
Null sub-carriers		92	104	184	184
Pilot sub-carriers		60	136	120	280
Data sub-carriers		360	272	720	560
Sub-channels		15	17	30	35
Symbol period, Ts (microseconds)		102.9			
Frame duration (milliseconds)		5			
OFDM symbols/frame		48			
Data OFDM symbols		44 (32:DL/12:UL)			
Mod.	Code rate	DL (Mb/s)	UL (Mb/s)	DL (Mb/s)	UL (Mb/s)
QPSK	1/2 CTC 6x	0.38	0.11	0.77	0.22
	1/2 CTC 4x	0.58	0.16	1.15	0.34
	1/2 CTC 2x	1.15	0.33	2.30	0.67
	1/2 CTC 1x	2.30	0.65	4.61	1.34
	3/4 CTC	3.46	0.98	6.91	2.02
16QAM	1/2 CTC	4.61	1.31	9.22	2.69
	3/4 CTC	6.91	1.96	13.82	4.03
64QAM	1/2 CTC	6.91	–	13.82	–
	2/3 CTC	9.22	–	18.43	–
	3/4 CTC	10.37	–	20.74	–
	5/6 CTC	11.52	–	23.04	–

DL: Downlink
UL: Uplink

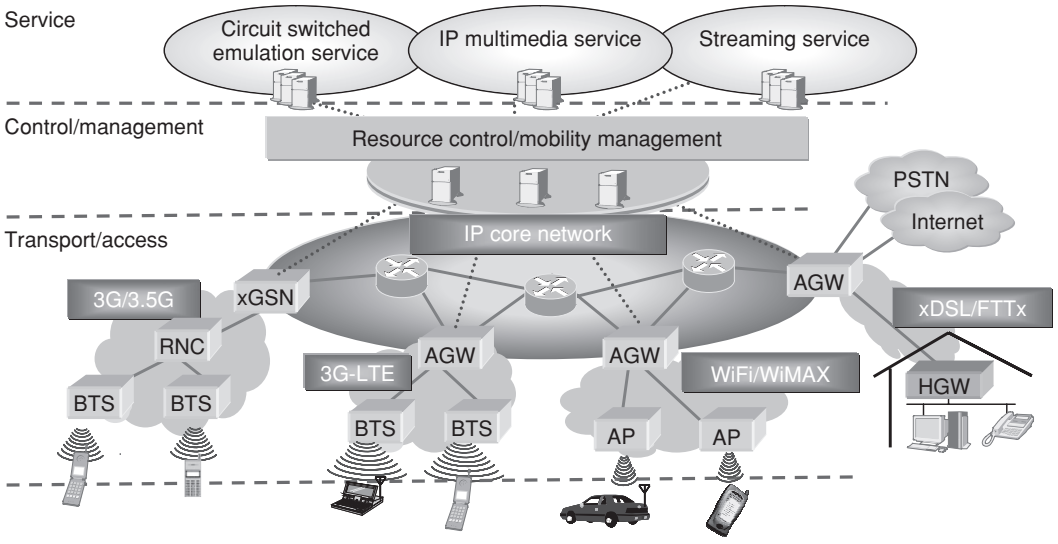
for Mobile WiMAX are shown in **Figure 3**.

The first model is a fixed application in which Mobile WiMAX is used as a fixed broadband service such as a replacement for digital subscriber line (DSL) access. Of course, there is Fixed WiMAX for this area. However, a lot of carriers would like to use Mobile WiMAX instead of Fixed WiMAX. This is because Fixed WiMAX system currently is not so popular and the system cost is relatively high.

The second model is a hot zone application. For this purpose, there are three usage categories: data-centric, rich-media-centric, and voice-centric. For data-centric usage, Mobile WiMAX is used to keep the data transmission rate high when a notebook personal computer (PC) or personal digital assistant (PDA) is used. This service is almost the same as the current HSDPA/HSUPA (high-speed downlink/uplink packet access) service in the 3G system. However Mobile WiMAX can provide a higher data transmission rate at a relatively low cost. For the rich-media-centric usage, there are two main uses that can be considered: satellite and cable television (CATV) broadcasting through WiMAX and data transmission from a user's personal media assistant. This application is very suitable for Mobile WiMAX because it needs a very high data transmission rate. For the voice-centric usage, voice-over-IP (VoIP) technology is applied to the Mobile WiMAX system. Although the 2G/3G cellular communication systems already have a legacy voice communication function in the system, WiMAX does not. Therefore, this function may be necessary to cover voice applications.

The third model is a hot zone with cellular system application. This application is a combination of Mobile WiMAX and a cellular system such as 2G or 3G. This application requires a dual-mode mobile phone, and the uncertain feasibility of dual-mode technology and its high cost might be a bottleneck.

One idea for a new mobile communication service using Mobile WiMAX is shown in **Figure 4**. This idea is for a user to send and



BTS: Base station transceiver
RNC: Radio network controller
xGSN: Serving/gateway GPRS support node
HGW: Home gateway
AGW: Access gateway
LTE: Long term evolution
FTTx: Fiber to the home/curb/premises, etc.

Figure 2
Next-generation packet-based network configuration.

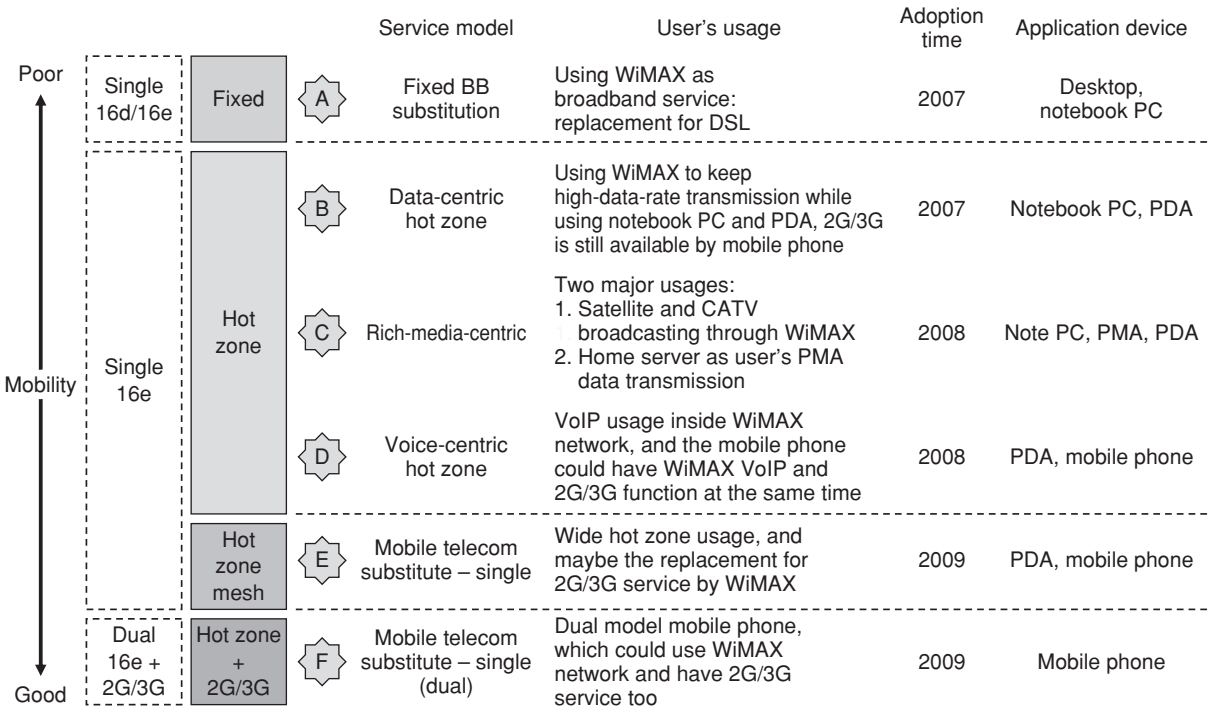
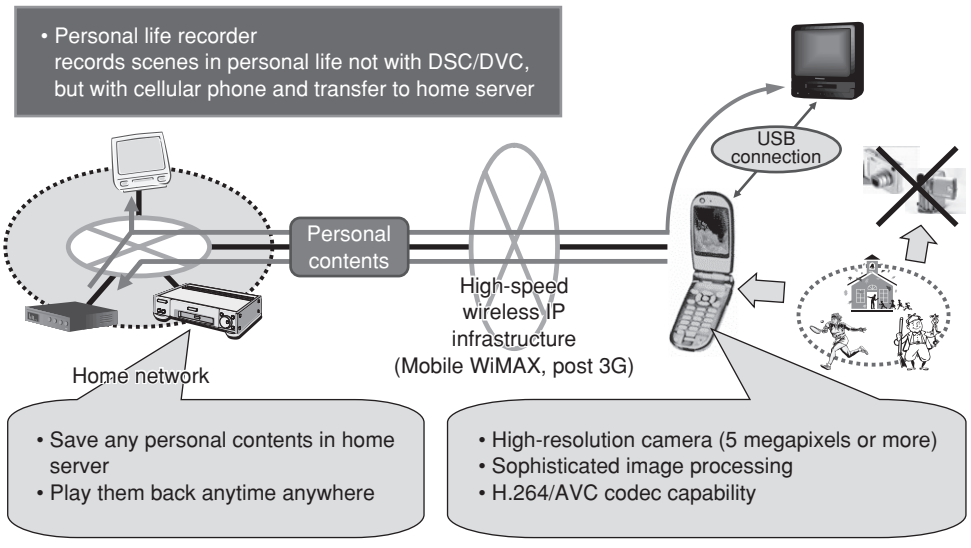


Figure 3
Service models of Mobile WiMAX.



DSC: Digital still camera
DVC: Digital video camera

Figure 4
New mobile communication service.

receive personal high-resolution pictures on a Mobile WiMAX terminal to/from a home server located in his/her home. In the current situation, to take a high-definition video picture, we use a digital still camera or digital video camera. If the camera's memory is full, we cannot record any more until some data has been deleted. However, if we can use wireless data transmission for personal video recoding, then the camera's memory capacity becomes irrelevant. Furthermore, this service enables playback of recorded personal videos. Via a Mobile WiMAX network, we can see personal videos that we recorded and stored on our home server wherever we are. Using a similar architecture, we can consider time-shift, location-shift TV-playback services, an on-demand package-less video rental service, and on-demand live video news service.

5. Fujitsu's challenges for Mobile WiMAX SoC solutions

To deploy Mobile WiMAX services on the market, we must overcome the challenges of developing Mobile WiMAX SoC solutions. Our current roadmap for SoC is shown in **Figure 5**. We plan to develop both baseband SoCs and RF LSIs for Mobile WiMAX terminals. For mobile applications, it is very important to make these SoCs or LSIs in a small size with very low power consumption. In 2007, we released the generation-1 baseband (BB) SoC (MB86K21) for notebook PC applications such as PCMCIA cards and USB-dongle WiMAX modules. The BB SoC has CardBus and USB interfaces for the module and uses 90-nm CMOS technology. We developed reference design kits (PC card type)[10] and system development kits[10] to enable customers to develop Mobile WiMAX products easily. We also performed a lot of interoperability tests (IOTs), such as WiMAX Forum Plugfest and private IOTs, to confirm that our BB SoC works well under the WiMAX Forum's Mobile WiMAX System Profile version 1.5.0.

For a generation-2 BB SoC, we use an advanced 65-nm CMOS process to achieve high performance and low power consumption. At the same time, we developed a generation-2 RF LSI and power management module (PMM) to create a complete solution that enables a customer to make a PDA product or mobile-phone-type

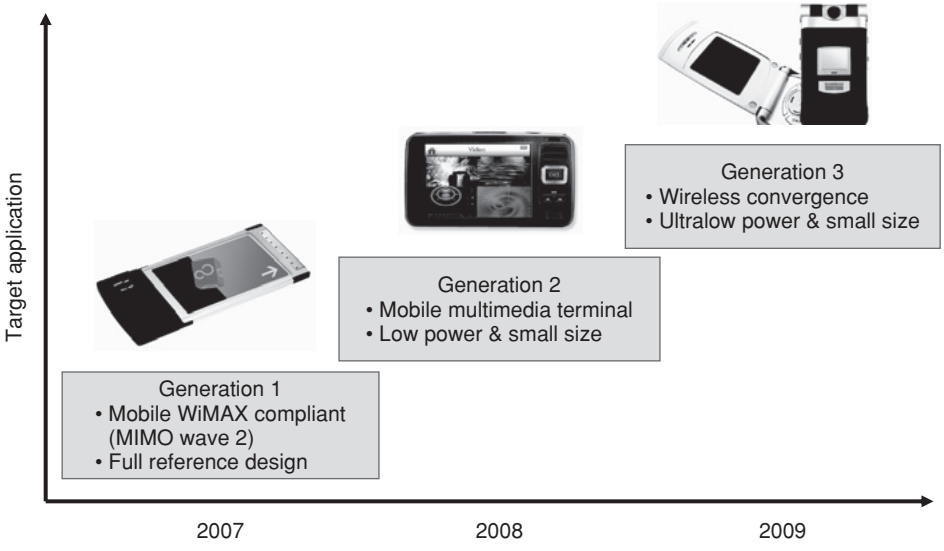


Figure 5
Roadmap of our SoC developments.

WiMAX product.

For the PMM, we applied a precise power management scheme to achieve ultralow power consumption. The main features of the PMM are as follows.

- Hierarchical power management scheme supported by new chip sets from Fujitsu.
- During data communication, the clock gating scheme is mainly applied to the digital part of the WiMAX chip set. A power gating scheme is applied to the RF section, including the power amplifier, and analog front-end, e.g., the analog-to-digital and digital-to-analog converters in the chip sets.
- Fujitsu's power gating scheme supports "on-chip power switch integration" and "auto-retention SRAM macros" (SRAM: static random access memory).
- In active mode, the entire power control scheme is executed on an ARM processor.
- In standby mode, the entire power supply for the chip sets will be shut down, except for the PMM and power management unit (PMU) in the SoC.
- The PMM supplies all the various voltages needed for the WiMAX chip set using only a single battery as its power source.
- It satisfies the requirement to reduce active and standby power automatically.

The main features of our generation-2 solution are as follows.

- Low cost and full compliance with the IEEE 802.16e-2005 Mobile WiMAX standard
- Very small handset module
- RF, BB SoC, PMM, Flash, SDRAM, and all passive components including built-in upper and lower MAC (LMAC/UMAC) as firmware
- Target profile: 2A/B/C, 3A, 5AL/BL/CL with 20-MHz channel bandwidth
- Host interface: SPI/SDIO

For generation 3, our target is to get a Mobile WiMAX terminal to coexist with WiFi/BT and various cellular phone systems such as 2.5G, 3G, and 3.5G.

Regarding the RF LSI, we have already announced the launch of the world's smallest RF module,[4] MB86K71, for mobile devices. It supports all of the RF circuitry necessary for Mobile WiMAX, including RF-IC, antenna switches, a power amplifier, filters, and an oscillator circuit, but still measures only 15 mm × 15 mm (height: 1.5 mm). This generation-1 RF module supports multiple-input multiple-output (MIMO) technology, thereby enabling high-speed and reliable wireless connections that are essential for Mobile WiMAX devices. Furthermore, we also verified that this RF module can be connected to our previously released Mobile WiMAX baseband chip MB86K21, enabling customers to achieve faster development and faster time to market for Mobile WiMAX devices through the use of both chips. In addition, we plan to develop a generation-2 RF LSI to further reduce the size and power consumption.

6. Conclusion

Mobile WiMAX is a creditable candidate system for providing high-speed-data access services to users. In this paper, we summarized the specific features of Mobile WiMAX and a generic network configuration for a next-generation core network. Then, we introduced candidate services for Mobile WiMAX. Finally, we mentioned our challenges for Mobile WiMAX SoC solutions. We have already developed both a BB SoC, MB86K21, and an RF module, MB86K71. These solutions enable a customer to develop Mobile WiMAX products that are small and have low power consumption. We will continue to develop the generation-2 BB SoC and RF LSI to achieve even smaller and lower-power-consumption solutions for customers.

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