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듀얼모드 LTE-FDD/TDD 및 듀얼모드 WiMAX-TDD/LTE-TDD에 대한 실현가능성 연구

On the Feasibility of Dual Mode LTE-FDD/TDD and Dual Mode WiMAX-TDD/LTE-TDD

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요 약 FDD를 사용하는 영역에서는 LTE-FDD가 "4G" 무선 광대역 엑세스의 강력한 후보기술의 하나로 여겨지는 한편, 최근 LTE-TDD가 TD-SCDMA의 진화 경로 및 일부 경우에는 WiMAX-TDD에 대한 진화 경로로서 떠오르고 있다. 본 논문에서는 LTE-TDD에 관하여 다음의 두 가지 조합의 듀얼모드 구현에 대한 실현가능성을 분석한다: 듀얼모드 LTE-FDD/TDD 및 듀얼모드 WiMAX-TDD/LTE-TDD. LTE-FDD 및 LTE-TDD 사이의 시스템 파라미터, 용어사용 및 프레임 구조에서의 공통성에 따라 듀얼모드 LTE-FDD/TDD가 비용면에서 효율적으로 구현이 가능함을 보인다. 또한, 스케줄링 알고리즘, 제어 메카니즘 및 지원하는 스펙트럼 대역에서의 공통성에 따라 듀얼모드 WiMAX-TDD/LTE-TDD 역시 비용면에서 효율적으로 구현이 가능함을 보인다. 시스템 파라미터 및 프레임 구조에서의 공통성은 칩을 구현하는데 매우 중요한 부분이며, 알고리즘 및 제어 메카니즘에서의 공통성은 구현된 칩이 얼마나 잘 동작하느냐에 매우 중요한 부분임을 주목한다.

Abstract While Long Term Evolution-Frequency Division Duplexing (LTE-FDD) is regarded as one of the strong candidates for "4G" wireless broadband access in FDD field, LTE-Time Division Duplexing (TDD) is emerging as one possible migration path for WiMAX-TDD in some cases as well as the migration path for Time Division-Synchronous Code Division Multiple Access (TD-SCDMA). In this paper, we analyze the feasibility of dual mode with LTE-TDD in two combinations: dual mode LTE-FDD/TDD and dual mode Worldwide Interoperability for Microwave Access (WiMAX)-TDD/LTE-TDD. Thanks to the commonality in numerology, terminology, and frame structure between LTE-FDD and LTE-TDD, dual mode LTE-FDD/TDD looks feasible in a cost-effective manner. Thanks to the commonality in scheduling algorithm, control mechanism, and supported spectrum bands, it is shown that dual mode WiMAX-TDD/LTE-TDD looks feasible as well. It should be also noted that the commonality in numerology and frame structure is critical for building a chip while the commonality in algorithms and control mechanisms is critical to make it work.

Key Words : Dual mode, WiMAX, LTE, FDD, TDD

Ⅰ. Introduction

In recent years, the demand for mobile Internet access has grown significantly. So, the capabilities of wireless networks are continuously being enhanced to meet ever growing demand of the higher data rates for accessing wide range of internet services in the mobile node. The International Telecommunication Union's (ITU) Working Party 5D (WP 5D) launched the

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International Mobile Telecommunications (IMT)-Advanced initiative, seeking proposals from communication standards organizations regarding 4G technologies[1]. They've received several proposals, mainly based on two technologies: WiMAX, which refers to IEEE 802.16 family of standards and LTE, developed by the 3rd Generation Partnership Project (3GPP). Therefore, WiMAX and LTE are regarded as the technologies for so-called "beyond 3G" or "4G" wireless broadband access.

The first release of WiMAX Release 1.0 based on IEEE 802.16e standards has been deployed in many markets including South Korea, US, Japan, Russia, Taiwan, Malaysia, and so forth. LTE is recently gaining a lot of momentum as well mainly from the existing telecommunication industry, and LTE-FDD is regarded as the migration path for Wideband Code Division Multiple Access (WCDMA), High Speed Packet Access (HSPA), Global System for Mobile communications (GSM), Evolution Data Optimized (EVDO), and many other systems. At the same time, LTE-TDD* is emerging as one possible migration path for WiMAX-TDD in some cases as well as the migration path for TD-SCDMA.

Since LTE-FDD and LTE-TDD are being developed by the same standard development organization (SDO), 3GPP, with the maximized commonality between the two systems, it is likely that there can be deployment scenarios where LTE-FDD and LTE-TDD are operating simultaneously which requires the dual band LTE-FDD/TDD. Since LTE-TDD is regarded as one possible migration path for WiMAX-TDD, it is also likely that there can be deployment scenarios where WiMAX-TDD and LTE-TDD coexist. In order to ensure the smooth migration from WiMAX-TDD to LTE-TDD, the dual mode WiMAX-TDD/LTE-TDD is required. Therefore, in this paper, we analyze the feasibility of dual mode with LTE-TDD in two combinations: dual mode LTE-FDD/TDD and dual mode WiMAX-TDD/LTE-TDD. Regarding dual mode among these systems, there has not been extensive analysis in the industry on the feasibility throughout the entire system including baseband implementation, RF implementation, scheduling and other control mechanism, and network-side aspects.

This paper is organized as follows. First, the feasibility of dual mode LTE-FDD/TDD is analyzed in details in Section II. Secondly, the feasibility of dual mode WiMAX-TDD/LTE-TDD is extensively analyzed in Section III. Then, we conclude the feasibility analysis in Section IV.

II. Dual Mode LTE-FDD/TDD

In this section, the feasibility of dual mode LTE-FDD/TDD is analyzed in various aspects such as baseband implementation, spectrum and RF implementation, scheduling, and network-side integration.

1. Baseband Implementation Aspects

Unlike 3GPP UMTS Terrestrial Radio Access (UTRA) where UTRA-FDD[2] and UTRA-TDD[3] are based on different technical specification (TS) documents, 3GPP LTE-FDD and LTE-TDD are based on the same TS document[4]. It means that the commonality between LTE-FDD and LTE-TDD is maximized to ensure the easy implementation of dual mode system as well as comparable performance between the two. Two main advantages in implementing dual mode system are the same numerology and the similar frame structure.

Since both systems are developed in 3GPP, LTE-FDD and LTE-TDD are using the same terminology and numerology. Table 1 shows OFDM parameters which are common across LTE-FDD and LTE-TDD. As shown in Table 1, LTE-FDD and LTE-TDD can be implemented with the same

* LTE-TDD is also called as TD-LTE especially in China to emphasize the fact that LTE-TDD (or TD-LTE) is the migration path from TD-SCDMA.

sampling clock if channel bandwidths are the same or the very similar sampling clock (multiples of 3.84 MHz) even if channel bandwidths are different.

표 1. LTE시스템의 OFDM 파라미터
Table 1. OFDM parameters of LTE system

Channel BW [MHz]	1.4	3	5	10	15	20
Subcarrier Spacing [kHz]	15	15	15	15	15	15
Number of Resource Blocks	6	15	25	50	75	100
Number of Subcarriers	73	181	301	601	901	1201
FFT Size	128	256	512	1024	1536	2048
Sampling Rate* [MHz]	1.92 (1/2× 3.84)	3.84	7.68 (2× 3.84)	15.36 (4× 3.84)	23.04 (6× 3.84)	30.72 (8× 3.84)

Figure 1 shows the frame structure of LTE where type 1 frame structure is for FDD operation and type 2 is for TDD operation. Across FDD and TDD, almost all parameters such as radio frame duration (10 ms), slot duration (0.5 ms), and sub-frame duration or transmit time interval (TTI) duration (1 ms) are common except the presence of special sub-frame in TDD which is for switching from downlink (DL) to uplink (UL).

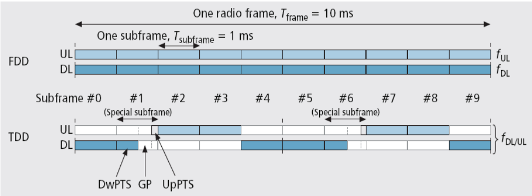

그림 1. LTE 프레임 구조: FDD용 타입1 및 5ms 스위치-포인트 주기를 갖는 TDD용 타입2
Fig. 1. LTE frame structure: type 1 for FDD and type 2 for TDD with 5 ms switch-point periodicity

2. Spectrum and RF Implementation Aspects

Table 2 shows LTE operating bands defined by 3GPP[5]. As shown in Table 2, there are 19 bands defined for FDD operation and 8 bands defined for TDD operation as of June 2010. Among those, major operators who are planning to deploy LTE-FDD networks are expected to use band 1, 7, 12-17, and 11/21 which are 2 GHz, 2.5 GHz, 700 MHz, and 1.5 GHz, respectively. On the other hand, LTE-TDD is expected to be deployed in band 38 and 40 which are 2.5 GHz and 2.3 GHz, respectively. The focused spectrum bands in LTE-FDD and LTE-TDD are different, so dual band RF circuitry may be required to implement dual mode LTE-FDD/TDD system.

Even in a situation where LTE-FDD and LTE-TDD are using the similar frequency band, TDD systems avoid the need for expensive duplexers (or diplexers) and require significantly less components in transceiver implementation compared to FDD system. TDD requires only one branch in its transceiver since the one branch can be shared among transmission and reception, but FDD requires two parallel branches: one for transmission and the other for reception. Therefore, dual mode implementation of LTE-FDD/TDD requires higher cost especially in its RF portion compared to LTE-TDD single mode.

In short, there is less commonality between LTE-FDD and LTE-TDD in spectrum and RF implementation aspects due to global spectrum arrangement and fundamental difference between FDD and TDD systems.

표 2. 3GPP에 의해 정의된 LTE 동작 대역
Table 2. LTE operating bands defined by 3GPP[5]

LTE Band	UL band [MHz]	DL band [MHz]	Duplex Mode
1	1920-1980	2110-2170	FDD
2	1850-1910	1930-1990	
3	1710-1785	1805-1880	
4	1710-1755	2110-2155	
5	824-849	869-894	
6	830-840	875-885	
7	2500-2570	2620-2690	
8	880-915	925-960	
9	1749.9-1784.9	1844.9-1879.9	
10	1710-1770	2110-2170	
11	1427.9-1447.9	1475.9-1495.9	

* Sampling rate is the product of subcarrier spacing and FFT size. E.g.) 3.84 MHz = 15 kHz × 256

12	698-716	728-746	
13	777-787	746-756	
14	788-798	758-768	
15,16	Reserved	Reserved	
17	704-716	734-746	
18	815-830	860-875	
19	830-845	875-890	
20	832-862	791-821	
21	1447.9-1462.9	1495.9-1510.9	
...			
33	1900-1920		TDD
34	2010-2025		
35	1850-1910		
36	1930-1990		
37	1910-1930		
38	2570-2620		
39	1880-1920		
40	2300-2400		

3. Scheduling and Other Aspects

There are 7 different DL-UL configurations defined in LTE-TDD as shown in Table 3*. The example TDD frame structure shown in Figure 1 was LTE-TDD frame structure with DL-UL configuration 1. Although numerology in frame structure is common across LTE-FDD and LTE-TDD, there are fundamental differences between the two. LTE-TDD system is always a half-duplexing system while LTE-FDD system is a full-duplexing system which can support both of full-duplexing FDD mobile stations (MSs) and half-duplexing FDD (H-FDD) MSs. In additions, DL and UL bandwidth ratio in LTE-TDD can be varying and can be asymmetric. For example, DL-to-UL ratio (or TDD ratio) can be up to 8:1 which is a DL heavy configuration where 8 subframes are allocated to DL and only 1 subframe is allocated to UL, and down to 1:3 which is a UL heavy configuration. These fundamental differences make the implementation and the operation of some algorithms different between LTE-FDD and LTE-TDD.

* In Table 3, D denotes DL subframe, UL denotes UL subframe, and S denotes special subframe where the DL-UL switch takes place.

표 3. LTE-TDD의 DL-UL 설정
Table 3. DL-UL configurations of LTE-TDD

DL-UL config	DL-UL switch-point periodicity	Subframe number									
		0	1	2	3	4	5	6	7	8	9
0	5 ms	D	S	U	U	U	D	S	U	U	U
1	5 ms	D	S	U	U	D	D	S	U	U	D
2	5 ms	D	S	U	D	D	D	S	U	D	D
3	10 ms	D	S	U	U	U	D	D	D	D	D
4	10 ms	D	S	U	U	D	D	D	D	D	D
5	10 ms	D	S	U	D	D	D	D	D	D	D
6	5 ms	D	S	U	U	U	D	S	U	U	D

First of all, scheduling should be different between LTE-FDD and LTE-TDD. LTE-TDD scheduler should be aware of the limitation of system (both of network and MS) that radio channel is not constantly available in each direction and no one can transmit and receive simultaneously. This limitation/constraint may lead to significantly different scheduling operation between LTE-FDD and LTE-TDD.

Secondly, HARQ process number and timing are different between LTE-FDD and LTE-TDD. For example, HARQ ACK/NACK for traffic sent in subframe n shall be transmitted in subframe $n+4$ in LTE-FDD. However, assuming that MS receives traffic in DL in subframe n, subframe $n+4$ may not necessarily be UL subframe for MS to send HARQ ACK/NACK in LTE-TDD system. This leads to different HARQ process number and different round trip delay (RTD) for control loops such as HARQ between LTE-FDD and LTE-TDD.

Other than the above, several other things such as power control timing, sounding reference signal (SRS) configuration, and PRACH configuration (density and frequency/time position) are different between LTE-FDD and LTE-TDD.

4. Network-side Aspects

Figure 2 shows LTE network architecture including Evolved-UMTS Terrestrial Radio Access Network (E-UTRAN) and Evolved Packet Core (EPC). eNB is the base station (BS) which is responsible for all radio-related functions and activities. Mobility Management Entity (MME) hosts a lot of functions such as Non-Access Stratum (NAS) signaling and signaling security, idle state mobility handling, Packet Data Network Gateway (PDN GW) and Serving GW selection, and authentication. Serving GW is local mobility anchor point for inter-eNB handover which does packet routing and forwarding, and transport level packet marking in DL and UL. PDN GW is a node which allocates IP address to User Equipment (UE) and does per-user based packet filtering. EPC is quite transparent to duplexing schemes, so LTE network shown in Figure 2 can be used for both LTE-FDD and LTE-TDD as long as eNB supports the both systems.

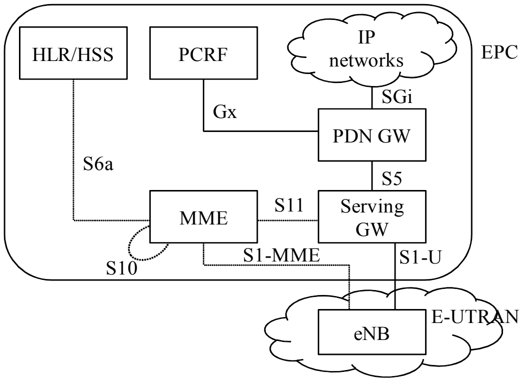

그림 2. E-UTRAN 및 EPC를 포함하는 LTE 망 구조
Fig. 2. LTE network architecture including E-UTRAN and EPC*

Ⅲ. Dual Mode WiMAX-TDD/LTE-TDD

In this section, the feasibility of dual mode WiMAX-TDD/LTE-TDD is analyzed in various aspects such as baseband implementation, spectrum and RF implementation, scheduling, and network-side integration.

1. Baseband Implementation Aspects

Since WiMAX and LTE are developed in different SDOs, IEEE and 3GPP, respectively, numerology and terminology are different between WiMAX-TDD and LTE-TDD.

Table 4 shows OFDM parameters of WiMAX system. As presented in Table 1 and Table 4, there is difference in nominal channel bandwidth, so eventually sampling rates are different between WiMAX-TDD and LTE-TDD. However, it is not very difficult to make different sampling frequency/rate with one reference clock.

표 4. WiMAX 시스템의 OFDM 파라미터
Table 4. OFDM parameters of WiMAX system

Channel BW [MHz]	5	7	8.75	10	20**
Subcarrier Spacing [kHz]	10.9375	7.8125	9.765625	10.9375	10.9375
Sampling Factor	28/25	8/7	8/7	28/25	28/25
Sampling Rate [MHz]	5.6	8	10	11.2	22.4
FFT Size	512	1024	1024	1024	2048

Another difference between the two systems is different terminology and different frame structure where WiMAX has 5 ms frame structure and LTE-TDD frame structure is as presented in Figure 1. Table 5 summarizes a loose link between the various channels, messages, signals in WiMAX and LTE. Quite different naming convention is used in two different systems, but it should be noted that there are always the counterpart in the other system for the channel, message, signal defined in one system. Therefore, fundamental function and operation can be similar to each other although external appearance in terms of terminology and mapping to the frequency-time resource grid in OFDM are different.

* Home Location Register (HLR), Home Subscriber Server (HSS), PCRF (Policy and Charging Rules Function)

** 20 MHz channel bandwidth is defined in IEEE 802.16e standards, but not included in WiMAX Forum Release 1.0 system profile[9].

표 5. WiMAX와 LTE사이의 여러 가지 채널, 메시지 및 신호 들 사이의 연관 관계
Table 5. Loose link between the various channels, messages, signals in WiMAX and LTE

LTE	WiMAX
Physical DL shared channel (PDSCH)	DL data burst
Physical broadcast channel (PBCH)	DL channel descriptor (DCD), Preamble
Physical multicast channel (PMCH)	DL data burst with multicast connection identifier (CID)
Physical control format indicator channel (PCFICH)	Frame control header (FCH)
Physical DL control channel (PDCCH)	DL/UL-media access protocol (DL-MAP, UL-MAP)
Physical HARQ indicator channel (PHICH)	HARQ_ACK IE
Cell-specific reference signal (RS)	Pilot signal - common
UE-specific RS	Pilot signal - dedicated
Synchronization signal	Preamble
Physical UL shared channel (PUSCH)	UL data burst
Physical UL control channel (PUCCH)	Channel quality indicator channel (CQICH), ACK channel, Bandwidth request ranging
Physical random access channel (PRACH)	Initial ranging, Handover ranging
Demodulation RS	Pilot signal
Sounding RS	Sounding signal

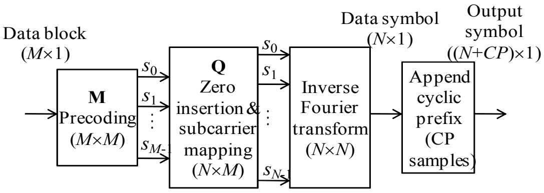

그림 3. 일반화된 MC 송신기
Fig. 3. Generalized MC transmitter

Besides numerology and terminology, there are several other critical differences between WiMAX and LTE such as UL multiple access schemes, Turbo coding architectures, and supported Multiple Input Multiple Output (MIMO) schemes.

Let's first investigate different UL multiple access schemes in WiMAX and LTE. Both of WiMAX and LTE are using orthogonal frequency division multiple access (OFDMA) as multiple access scheme in DL. However, UL multiple access schemes are different between the two systems since WiMAX is using OFDMA in UL as well but LTE is using single carrier-frequency division multiple access (SC-FDMA)* in UL[12]. This is one of the biggest differences between the two systems. Figure 3 presents baseband structure of a generalized multicarrier (MC) transmitter, which applies to all types of single-carrier (SC) or MC modulation signals transmitted in blocks. Information symbols (e.g., QAM symbols) are parsed into data blocks of size M. Data blocks belonging to a certain user are precoded with an $M \times M$ matrix $\mathbf{M}$. The precoded user-specific M-sized output is then mapped onto a set of M out of N inputs of the inverse discrete Fourier transform (IDFT) properly chosen by the user-specific subcarrier mapping $N \times M$ matrix $\mathbf{Q}$. Then, a cyclic prefix (CP) which is usually longer than the largest multipath delay is inserted before transmission to eliminate inter-symbol interference (ISI) arising from multipath propagation. If we consider a trivial case where precoding is performed with the identity matrix, $\mathbf{M} = \mathbf{I}_M$, the resulting scheme is OFDMA. If we use DFT as precoding scheme in $\mathbf{M}$, the resulting scheme is SC-FDMA. Therefore, it should be noted that SC-FDMA transmitter by default has OFDMA transmitter inside, which means that there is no additional block required for LTE-TDD transmitter to support WiMAX-TDD as well. Similarly, LTE-TDD receiver already has all necessary blocks for WiMAX-TDD reception as well.

LTE employs Turbo encoder which is a parallel concatenated convolutional code (PCCC) with two 8-state constituent encoders (mother code-rate is 1/3) and one internal interleaver (i.e., single-binary). WiMAX adopts Turbo encoder which uses a double binary circular recursive systematic convolutional code (mother code-rate is 1/3) with one internal interleaver

* SC-FDMA is also known as discrete Fourier transform spread-OFDM (DFTS-OFDM), and mostly used with frequency domain equalizer (FDE)[13].

(i.e., duo-binary). Also, the internal interleaver in LTE is a quadratic polynomial permutation (QPP) interleaver and the one in WiMAX is an almost regular permutation (ARP) interleaver. With the small difference between the two schemes, there are already many unified and/or scalable Turbo decoder implementations for multi-standard operation which can support high throughput with good area-efficiency and energy-efficiency[14,15].

Table 6 presents key MIMO techniques in WiMAX (Release 1.0 based on IEEE 802.16e) and LTE (3GPP Release 8). As presented in Table 6, the supported MIMO techniques are almost similar to each other except the support of close-loop operation and codebook-based Multiuser (MU)-MIMO in DL. Especially, it should be noted that both systems are not using SU-MIMO in UL, so only one power amplifier (PA) is required at MS side in both systems. In general, MIMO processing block in LTE system can support MIMO techniques defined in WiMAX system as well. There are already many works on the VLSI implementation of a multi-standard MIMO detector for WiMAX and LTE[16].

표 6. WiMAX와 LTE의 주요 MIMO 기술들
Table 6. Key MIMO techniques in WiMAX and LTE

Key MIMO Techniques	WiMAX (Release 1.0)	LTE (3GPP R8)
Open loop transmit diversity in DL	Supported	Supported
Open loop spatial multiplexing (SM) in DL	Supported	Supported
Open loop transmit diversity in UL	Not supported (implementation aspect)	Not supported (implementation aspect)
Open loop SM in UL (SU-MIMO)	Not supported	Not supported
Collaborative SM in UL (MU-MIMO)	Supported	Supported
Closed-loop antenna grouping/selection	Not supported	Supported
Closed-loop codebook-based precoding	Not supported	Supported
Closed loop multiuser MIMO in DL (MU-MIMO)	Not supported	Supported
Adaptive beamforming including DL SDMA	Supported	Supported

So far, the feasibility of dual mode WiMAX-TDD/LTE-TDD has been analyzed in basedband implementation aspects. Despites notable differences in numerology, terminology, and several key algorithms, it can be said that the two systems are not far from each other in terms of the actual implementation.

2. Spectrum and RF Implementation Aspects

Table 7 shows WiMAX Forum board of directors (BOD) approved mobile certification profile which is currently being used to certify the mobile WiMAX products[11]. The spectrum band of 1.A and 1.B is the same with LTE band 40 in Table 2, and the spectrum band of 3.A is the same with LTE band 38 in Table 2, respectively.

표 7. WiMAX Forum 이사회 승인된 mobile 인증 프로파일 (2009년 2월 기준)
Table 7. WiMAX Forum BOD approved mobile certification profiles (as of February 2009)

Profile numbering	Spectrum band	Channel BW	Duplex mode
1.A	2.3-2.4 GHz	8.75 MHz	TDD
1.B	2.3-2.4 GHz	5/10 MHz	TDD
3.A	2.496-2.69 GHz	5/10 MHz	TDD
5.AL	3.4-3.6 GHz	5 MHz	TDD
5.BL	3.4-3.6 GHz	7 MHz	TDD
5.CL	3.4-3.6 GHz	10 MHz	TDD

One key component in RF part is a PA. The main advantage of SC-FDMA compared to OFDMA is reduced peak-to-average power ratio (PAPR) which results in higher PA efficiency and cheaper MS implementation. Therefore, it is true that WiMAX RF requires better PA than LTE in terms of the linearity while LTE baseband requires more blocks than WiMAX. However, there are many works on linear PA development which are for both of WiMAX and LTE applications with high output power, good error vector magnitude (EVM) performance, and reasonable power consumption[17,18].

In additions, antennas are also very important in RF implementation. It is possible to design multi-band and multi-mode antenna for multi-standard including WiMAX and LTE as well as the other technologies such as GSM, PCS, and WLAN[19].

Other than the works on PA and antenna, there are many other works on dual mode WiMAX-TDD/LTE-TDD such as the receiver front design[20], ADC design[21], etc.

Please note that there are already many WiMAX products which support 1.A, 1.B, and 3.A profiles without requiring multiple RF branches, which means that single RF branch can support from 2.3 GHz up to 2.69 GHz in WiMAX*. Seeing the feasibility of key RF components in supporting both of WiMAX and LTE, it is said that WiMAX certification profiles 1.A, 1.B, 3.A and LTE bands 38, 40 can be supported by single RF branch with dual mode WiMAX-TDD/LTE-TDD capability. This fact highlights the feasibility of dual mode WiMAX-TDD/ LTE-TDD.

3. Scheduling and Other Aspects

One big commonality across WiMAX-TDD and LTE-TDD is duplexing scheme, namely TDD, where radio channel is not simultaneously available in both of DL and UL. This makes scheduling mechanisms of WiMAX-TDD and LTE-TDD similar to each other.

In additions, TDD has channel reciprocity where DL channel condition and UL channel condition are the same if TDD switching is sufficiently fast compared to channel variation in time domain and DL/UL circuitries are compensated properly. This channel reciprocity can help scheduler to perform channel-aware scheduling more efficiently.

Furthermore, channel reciprocity can be used in smart antenna techniques which can provide better spectral efficiency and coverage in cellular deployment. In general, BS with smart antenna techniques or beamforming techniques requires DL channel state information (CSI) to make appropriate beam shapes and patterns. Since MS estimates DL CSI by receiving DL pilots or reference signals, MS needs to feedback this CSI to BS, which results in closed loop operation. However, in TDD, BS can efficiently retrieve DL CSI from UL CSI where UL CSI can be obtained directly at BS by receiving UL signal such as sounding (reference) signal. This removes the requirement of CSI feedback in UL and this can apply to both of WiMAX-TDD and LTE-TDD system.

4. Network-side Aspects

LTE network architecture was presented in Figure 2. Figure 4 presents the similarity between WiMAX network architecture and LTE architecture focusing on the functions of each node in the network. WiMAX access service network (ASN) is comprised of BS and ASN-gateway (ASN-GW). As shown in Figure 4, ASN-GW functions are actually the combination of MME functions and Serving GW functions in LTE network. Therefore, it is purely an implementation issue whether manufacturers build the one equipment which can support both of WiMAX's ASN-GW functions and LTE's MME/Serving-GW functions, and this does not require large amount of additional efforts. Already there are some works on combining WiMAX and LTE gateway functions[22].

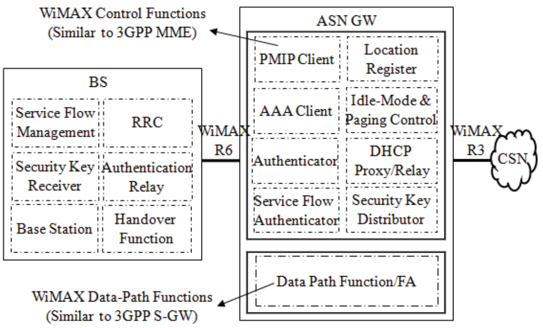

그림 4. WiMAX 망 구조 및 ASN-GW와 MME/Serving-GW와의 유사성
Fig. 4. WiMAX network architecture and the similarity between ASN-GW and MME/Serving GW

Since IEEE 802.16m provides backward compatibility to the previous version, IEEE 802.16e, migration from IEEE 802.16e to IEEE 802.16m can be

* These RF solutions generally support WiFi in 2.4 GHz band as well.

very smooth. In addition to this migration story, there are some discussions on the possible migration from IEEE 802.16e to LTE-TDD as well. The two technologies have the same foundations of MIMO+OFDMA and have a large number of similar if not identical features which can greatly simplify this migration. WiMAX and LTE-TDD core networks are both IP-based and have many other similarities. The evolution of WiMAX core network to support LTE-TDD core network can be largely, if not completely, handled by software upgrades of WiMAX core components. As such, none of WiMAX hardware components become redundant during this migration.

During the migration, if an operator wants to add LTE-TDD on top of its existing WiMAX network where WiMAX and TD-LTE must co-exist, new LTE-TDD core functions are added. Some of LTE-TDD's EPC functions could be added (largely by software upgrades) to the existing WiMAX components. One example of adding LTE-TDD's EPC functions to WiMAX network can be as follows: Serving-GW function is added as a software upgrade to ASN-GW, PDN-GW function is added as software upgrade to home agent (HA), MME function can be added as a new hardware component or as a software upgrade to ASN-GW, HSS function can be added as a software upgrade to WiMAX Authentication, Authorization, and Accounting (AAA) server, and PCRF function can be added via a new hardware component for serving both WiMAX and TD-LTE. This together with dual mode WiMAX-TDD/LTE-TDD can ensure smooth migration from IEEE 802.16e to LTE-TDD as well.

V. Conclusions

In this paper, we analyzed the feasibility of dual mode LTE-FDD/TDD and dual mode WiMAX-TDD/LTE-TDD, respectively. Given the fact that LTE-FDD and LTE-TDD are developed in the same SDO, 3GPP, it shares a lot in common including numerology, terminology, frame structure, network architecture, etc. And this commonality makes it easier to build LTE-FDD/TDD together on a same chip. However, the fundamental difference between FDD and TDD makes it difficult to use the same scheduling algorithms and the same control mechanisms across the two systems. So, it still takes major efforts to make each FDD and TDD portion work properly in the dual mode system. On the other hand, WiMAX-TDD and LTE-TDD look different from each other in numerology, terminology, frame structure, etc. Although it can make it little more difficult to build the two systems on a same chip compared to LTE-FDD/TDD case, these two systems share a lot in common in scheduling algorithms, control mechanisms, and RF implementation in terms of the focused spectrum bands. Furthermore, it is also shown that LTE-TDD's EPC functions and WiMAX's network functions are similar to each other, so these can be built together by maximizing the common/sharing portion. Through the extensive analysis in this paper, it is shown that both of dual mode LTE-FDD/TDD and dual mode WiMAX-TDD/LTE-TDD look feasible in a cost-effective manner. It should be also noted that the commonality in numerology and frame structure is critical for building the chip, but the commonality in algorithms and control mechanisms is critical to make it work.

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