Migration from WiMAX to LTE in the radio network – a brief analysis

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1 Introduction

The development of LTE, the 4th generation progeny of UMTS, is lagging approximately 3 years behind the development of WiMAX. However, it is clear that over the next few years, both LTE and WiMAX will compete for marketshare in the broadband wireless access market. While there is a lot of speculation as to who will ultimately succeed, for many vendors, it is imperative to have a product offering in both access technologies. LTE and WiMAX use fundamentally similar technologies, the task; however, for an existing WiMAX network equipment vendor, to migrate to LTE can be somewhat daunting. In this document, we lay out the top few challenges from our perspective. The discussion will range from the technical considerations due to changes in the air-interface, to the practical considerations for implementation.

It should be noted that the standards for WiMAX and LTE, both offer many options for implementation. Instead of doing an exhaustive comparision of all possible options, we shall restrict ourselves to the most likely/natural implementations.

This document is organized as follows:

- In the next section, we will discuss the key differences in the two wave-forms, subdivided into categories. We do not intend to provide an exhaustive analysis; our focus is on what we believe are the key areas and the major differences.
- In the 3rd section, we will discuss the differences in radio resource organization and channel management.
- In the 4th section, we will discuss the differences in IP packet transfer over the airlink
- In the 5th section, we will discuss the differences in mobility and other radio network functions.

2 Comparison of the LTE and WiMAX waveforms

2.1 The downlink

LTE and WiMAX both use slightly different technologies in the forward layer. Whereas LTE uses OFDM, WiMAX (predominantly) uses OFDMA[1]. From the physical waveform perspective, the difference between the two are not very large[2].

The most common configuration for WiMAX uses the TDD mode of operation. The WiMAX downlink is subdivided into frames; while a range of sizes are supported, 5ms is common feature. The WiMAX specification offers multiple FFT sizes, all of which are in powers of 2. The largest FFT size is 2048.

If we compare with LTE, the most common configuration (outside of China) is the FDD mode. The LTE spec supports multiple FFT sizes, out of which one (corresponding to 15Mhz) is of size 1536, which is not a power of 2. The largest size is also 2048, corresponding to 20Mhz.

Downlink processing can be split up into three separate stages, as shown in the diagram below.

<add diagram>

Stage 1 converts the layer 2 payload (control or data) to encoded bit-streams. Stage 2 converts the encoded bit-streams to IQ samples and stage 3 converts the IQ sample stream to an output wave-form. While the

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[1] An OFDM version of WIMAX exists, but most of the implementations we know of use OFDMA

[2] The impact on the MAC layer is much more significant.

actual implementation may or may not match this model, we shall use it as a convenient mechanism for comparing the two technologies.

2.1.1 Frequency diversity modes

WiMAX supports frequency diversity in the form of permutations, the most standard ones being FUSC and PUSC. Corresponding to these, LTE defines virtual resource block assignments. Depending on the available bandwidth, there are two kinds of distributed virtual resource block assignments possible achieving different diversities.

First, a note on terminology. Both LTE and WiMAX use the concept of sub-carriers. In WiMAX, multiple sub-carriers are organized into sub-channels and then sub-channels, combined with OFDM make OFDM slots. For example, in downlink FUSC, one slot comprises of one sub-channel in the frequency domain, with one symbol in the time-domain. Frequency permutation determines the mapping of individual sub-carriers to a sub-channel. Thus, in FUSC mode (2048 point FFT), each sub-channel comprises of 48 data-subcarriers spread out over the entire bandwidth.

The corresponding term in LTE for the slot is the resource block, and for the sub-channel is the radio-bearer. A resource block comprises of a set of OFDM symbols (6 or 7, depending on the preamble length) and a fixed number of sub-carriers. The sub-carriers are always continuous in a radio-bearer. However, individual allocated radio bearers are spread over the entire available bandwidth with one of two possible gap values. For example, if the system bandwidth comprises of say 70 radio-bearers, (12 sub-carriers to each radio-bearer), then the gap between allocations can be as either 32 or 16; i.e. consecutive virtual radio-blocks shall be spaced apart by 16 or 32 physical radio-blocks (192 or 384 physical sub-carriers). Thus, the frequency diversity modes in LTE are closer to the clustering concept of PUSC.

2.1.2 Resource Element Groups

Resource element groups are somewhat analogous to the feedback channels defined in WiMAX. However, while assignment of feedback channels in WiMAX is relative to a fast-feedback region, whose location is dynamically assigned (via the uplink map, uiuc=0), in LTE, the resource element groups within a particular resource block are statically assigned.

<add diagram, resource element groups>

As in WiMAX, the REGs can be used for multiple purposes

- HARQ Ack/Nak signaling through the PHICH
- Control Channel Format signaling through PCFICH
- Resource allocation signaling through PDCCH

2.1.3 OFDM symbol creation

There are minor differences between the OFDM symbol generated by LTE in the downlink and the OFDMA symbol generated by WiMAX. The key difference is in the cyclic prefix insertion. Whereas WiMAX allows for four types of Cyclic Prefixes, defined in terms of the symbol duration, LTE defines two absolute values of cyclic prefix. The cyclic prefix length for normal transmission is 160 in the 0th time-slot and 144 in the subsequent. In extended mode, this goes up to 512.

2.1.4 System Acquisition signals

In any wireless system, reference signals are transmitted, so as to aid system acquisition by user-terminals. In WiMAX, this includes detecting the signal (bandwidth, carrier spacing), reading the cell-identity, and then start reading the downlink map, which indicates the location of the next channel descriptor messages. The channel descriptors provide enough information for the user terminal to start planning the registration phase.

In LTE, the organization of the same information is somewhat different.

- The carrier spacing in LTE is either 15Khz (standard) or 7.5Khz(usually only used in MBMS mode). Acquisition can be done either to pick up the central sub-carriers (which carry all the control channels) or a blind acquisition can be done at max FFT size to determine the size of the guard band on either edge of the spectrum.
- Once system acquisition is complete, the user terminal will read the transmissions on the packet broadcast channel, to get the key variables defining the physical channel. The packet broadcast channel is transmitted at a fixed offset from the center frequency.
- The information from the packet broadcast channel gives the user terminal sufficient information to start reading the Packet Downlink Common Control channel. This will identify the resources available to transmit the system acquisition, modes of

2.2 The uplink

As opposed to WiMAX, which uses a symmetric air-interface, LTE uses SCFDMA on the uplink. We won't go into the details of SCFDMA; it can be implemented by one additional FFT stage over the standard OFDM processing. More details are available [here].

Additionally, LTE defines frequency hopping in the uplink. The frequency allocation is divided into sub-bands of configurable size; a single user terminal can be required to do both inter-subband and intra-sub-band hopping, based on the requirements of the radio-channel.

3 Management of Radio Resources

3.1 Organization of radio-resources

A physical channel can be described as a set of related information, being transmitted over a given set of pre-defined (though not necessarily static) resources using a specific transmission format. Physical channels are commonly identified so as to simplify the job of the receiver when it is looking for some specific information.

In WiMAX, the concept of a physical channel is not very strongly defined; however, there do exist some transmissions which can qualify as physical channels. The examples are:

1. Pilot transmissions (see discussion on reference signals). These are placed in pre-defined locations (sometimes depending on the slot number) and carry specific information.
2. The downlink preamble always occupies a fixed time-slot at the head of the frame and covers the entire band.
3. The downlink frame prefix always is carried on the first sub-channel after the prefix in PUSC mode.

Pretty much everything else is signaled through the downlink map; this increases the options for the downlink frame scheduler, but also increases its complexity.

Additionally, we have the fast-feedback channel, which can be used for HARQ feedback, channel measurements, etc.

In LTE, a large number of physical channels are pre-defined. We will describe these individually below; note that the LTE definition of physical channel is not exactly the same as Wimax, so a straight-forward mapping from the specifications will not work. Broadly, the radio-resources can be divided as:

- Broadcast channel, used for system information transmission (analogous to some functions of the DCD/UCD)
- Control channel elements, including the downlink control channel, harq indicator channel and a special format indicator channel. The control channels together carry HARQ feedback, resource allocation and power control parameters in the downlink. In the uplink they carry measurements and power headroom reports. Thus, the control channel elements put together broadly map to the fast-feedback channel.

3.1.1 Physical Downlink Control Channel

The physical downlink control channel is carried in a fixed number of resource element groups (called CCEs), which are found at the same sub-frames in each slot, in the central sub-carriers. The PDCCH can be mapped to 1,2,4 or 8 sets of resource element groups, admitting 72, 144, 36 and 576 bits respectively. The PDCCH carries the DCI information, which is convolutionally coded at rate 1/3 and then QPSK modulated onto the selected CCEs.

Packet Downlink Control Channel	
Resource Mapping	1,2,4 or 8 CCEs.
Modulation	QPSK
Coding	R1/3
Rate Matching	Depends on the aggregation level.
Payload	Payload in the form of DCIs

3.1.2 Physical Downlink Shared Channel

The PDSCH is used to carry user data in the form of individual code-words. Each code-word is encoded using Turbo code, R1/3 and then sampled at a specific rate to achieve the appropriate code-word size. QPSK, 16QAM and 64QAM modulations are permitted.

The PDSCH code-words are preceded by a piece of information which identifies the transmission format (DCI, see below). The DCI of categories 1, 1A,1B, 1C,1D are used.

PDSCH code-words can be mapped onto any resource blocks which are not previously being used for other data transmission.

3.1.3 Packet Broadcast Channel Downlink

The downlink broadcast channel is used to carry system wide information, which is used by all mobile terminals as part of system acquisition. The PBCH is mapped onto 72 sub-carriers in the middle of the spectral band used for transmission, and the first four OFDM-symbols in sub-frame 0. PBCH consists of 1920 bits which are tail-biting convolutional coded at rate 1/3 and subsequently QPSK modulated, to get a total of 1920*3/2 = 2880 bits. The entire PBCH content is transmitted over 10 frames.

Most of the contents of the PBCH map roughly to the commands transmitted in Wimax either using (extended) DIUC/UIUCs (about the 12 reserved for data). The table below summarizes some of the key information.

3.1.4 HARQ Indicator channel

TBD

3.1.5 Uplink Control channel

The packet uplink control channel is used for transfer of control information by the user-terminal to the eNodeB. This control information consists of scheduling requests, measurement information and HARQ feedback. Thus it is similar to the uplink FAST_FEEDBACK channel in Wimax, except that it also allows for transmission of scheduling requests.

3.1.6 Uplink Shared channel

3.2 Resource allocation

Resource allocation in LTE (as in WiMAX) is dynamic; the resources available to an individual mobile are updated sub-frame by sub-frame. However, as opposed to WiMAX where resource allocations are made through a map, LTE handles resource allocations differently.

First of all, WiMAX resource units are in slots, whereas LTE defines resources in terms of code-words. A code-word is mapped to a set of radio-bearers and a given slot (corresponding to 6 OFDM symbols). The set of radio-bearers is describable as a bit-list and thus allows further interleaving of the frequency allocation for a given transmission.

The transmission of the DCI is one of the most complex operations in the LTE control channel transmission. We shall summarize how this happens below

- There are different DCI formats, each format being optimized for a specific type of communication. For example, format 1 and 1A refer to downlink allocations, 3 and 3A refer to transmit power control commands, 2 to spatial multiplexing etc.
- Each DCI is mapped onto one or more control channel elements with an added CRC. The CRC may be further scrambled, in order to differentiate between cell-specific and user terminal specific allocations.
- The user terminal may receive a combination of broadcast allocations as well as UE specific allocations.

- When a terminal receives a DCI it has to determine
    - The type of the DCI format
    - The length of the DCI message.

Neither of these are explicitly coded in the message, but have to determined using the cues from the DCI CRC, etc. For a given system configuration (number of downlink radio bearers, number of uplink radio bearers, number of ports), the size of each DCI format is pre-computable. Some of the interpretation is dependent on the exact RNTI which is used to scramble the CRC.

3.3 MIMO

Support for MIMO is built into LTE using the layering concept. 2X2, 2x4 and 4x4 MIMO modes are natively supported, in both spatial multiplexing (maximum throughput) and transmit diversity (maximum protection) modes. A choice of codebooks are specified in the LTE standard, and the UE and EnodeB can be configured to use one or the other of them. Further, the choice can be restricted. However, there are many features of Wimax MIMO that LTE does not support

1. LTE does not support dynamically computed code-books. However, the existing code-books can be restricted by configuration and signaling
2. Also, the maximum number of layers, even for four antenna MIMO operation is 2; the equivalent of Matrix C is not supported.
3. Space Time Coding is not supported in LTE
4. MIMO Midamble is not supported
5. Neither spatial multiplexing or transmit diversity modes are supported in the uplink

3.4 Power Control

LTE has a single power control mode for the UE uplink, which roughly corresponds to a combination of closed and open loop power control, except that all variables are controlled by the eNodeB. True open-loop power control as defined in WiMAX cannot exist, because the base-station or eNodeB returns no indication of received C/I to the user terminal. The key distinctions between WiMAX and LTE power control are:

1. There is no direct inclusion for the effects of the channel coding and modulation being used (e.g. Wimax open loop C/N figure)
2. As in Wimax there is a cell wide offset (equivalent to Offset_BSperSS) and a UE specific offset (Offset_SSperSS). However, both are controlled by the eNodeB as mentioned above. The objective of this portion of the power control formula is to have a static adjustment per cell and per SS (to handle cell-wide interference and position respectively) and a dynamic portion (discussed below) handling issues like fading.
3. An average path-loss term is used as in Wimax, however path loss estimation and filtering is done at the RRC level
4. There is an additional closed loop continuous correction term f(). f(i) is a sliding window averaging mechanism, allowing the power to drift upwards or downwards slowly, at a rate controlled by the eNodeB.

3.5 Channel quality reporting

As in WiMAX, LTE allows the eNodeB to configure the user terminal to provide a large number of measurements of multiple types. We summarize the main difference between Wimax and LTE as follows

1. There is no FAST_FEEDBACK channel in LTE. Measurements are sent periodically in the uplink control channels (PUCCH) and aperiodically (need based) on the PUSCH.
2. There is no equivalent of CINR or RSSI reporting. The CQI is an index into a table, suggesting the most aggressive combination of modulation and coding rate, which would permit a block to be received with block error rate no greater than 0.1. In effect, it is the suggested transmission configuration.
3. There is an option to transmitting the Rank Indication in case of MIMO operation; the RI indicates the number of seperate paths available, based on the rank of the channel quality matrix.
4. There is also an option of transmitting PMI, which corresponds to the mode-selection feedback in Wimax, except that the codebook is the one specified in the standard (or a subset thereof). There is no provision for dynamic generation of codebooks.

3.6 Hybrid ARQ implementation

Hybrid ARQ is a fundamental feature of LTE and is considered mandatory for each node and each transmission. Unlike Wimax, there is no special set of resources allocated (the HARQ map) for transmission of HARQ packets. Each and every transmission on the uplink/downlink shared channels are encoded for hybrid ARQ operation. The key differences are:

1. The only mode of hybrid ARQ encoding is incremental redundancy mode. Since all shared channel transmissions use a fixed encoding (turbo, rate 1/3), the sub-packets are generated by changing the puncturing rate. A maximum of 4 sub-packets can be generated for a single transport code-word.
2. Each UE-eNodeB pair supports multiple concurrent HARQ channels, upto a maximum of 8 in FDD mode. Multiple HARQ feedback channels are multiplexed onto a single harq indicator channel resource (harq group); the different feedback values are multiplexed using spreading codes. Thus the (HARQ group id, HARQ spreading sequence) tuple maps to the Ack Channel ID in Wimax. For formatting of the HARQ feedback information, see control channel definitions above.
3. HARQ transmission is a strictly binary operation, with the NDI (new data indicator) playing the role of the HARQ AI_SN.

4 Data delivery

As opposed to WiMAX, which utilizes a single MAC layer above the physical, LTE (in keeping with 3gPP standard procedures) uses the combination of an RLC, MAC (all layer 2 functions) and a Packet Data Convergence layer to interface between the IP and the physical. The combined functions of the PDCP+MAC is more or less equivalent to what the Wimax MAC provides. In this section, we shall consider some key functions where there are fundamental differences.

4.1 Media Access

Media access in LTE includes the initial access procedure, delivery of packets over the link layer and finally, DRX procedures for power saving.

4.1.1 Random Access Procedure

The random access procedure in LTE is rather similar to that in Wimax; the essential difference is that LTE does not use CDMA for the random access procedure. Instead, it uses a compressed SCFDMA transmission, with the subcarrier spacing at either 1.25Khz or 7.5Khz. The transmitted data contains a random number sequence with is generated using a Zadoff-Chu base with suitable cycle shifts, as commanded by the network.

<insert figure of the transmission sequence>

The sequence then undergoes a DFT, followed by an IDFT in the usual manner to be mapped onto the outgoing sub-carriers.

4.1.2 Link layer packet delivery

TBD

4.1.3 Sleep mode

The implementation of sleep mode or DRX (in LTE terminology) is much simpler than in Wimax. There is only one sleep state in the user terminal (as opposed to per CID sleep states in Wimax). There are two sleep modes (equivalent to the power saving classes), the long mode and the short mode. The UE starts sleep in either short mode or long mode; if in short mode it can, based on certain conditions, switch to the long mode. The DRX cycle is characterized by alternate periods of inactivity (no measurements, no monitoring of PDCCH for downlink assignments, no transmissions on PUCCH) and normal activity.

There are no trigger based events at the MAC level which can interrupt the inactivity state (possibly since the size of the inactivity period is fixed, not increasing as in PSC 3).

4.2 IP Convergence

In LTE, the IP convergence layer is called the PDCP; this layer intercepts tunneled IP packets from the terrestrial side of the base-station and transports IP packets over the air link to the user terminal (and vice versa). The primary functions of PDCP are:

- The ability to discard or forward packets on the appropriate link layer connection. Discarding can take place because of local timer expiry, or excessing reordering. This is a function explicitly defined for the base-station.
- Robust Header compression, similar to Wimax
- The security and ciphering functions (see below for further discussion)

PDCP does not add its own header, so in a way it is a silent convergence function; this is similar to Wimax.

4.3 Security

TBD

5 Radio Resource Functions

The LTE Radio-resource control function is significantly different from the equivalent functions in Wimax, both from a conceptual point of view as well as implementation details. One of the most significant differences, of course, is that LTE RRC explicitly has to handle older technologies such as CDMA2000, UMTS and GERAN, specially in cases of handover. We will not deal with this aspect in this section.

5.1 General management of radio-resources

The general management of radio-resources between the LTE eNodeB and the user terminal is shown conceptually in the diagram below

<add diagram>

Unlike Wimax, there is an explicit RRC connection between the eNodeB and the user terminal, which is used to transmit radio-related messages. In Wimax terminology, this may be roughly mapped to the ISF; however note that this is dedicated to RRC level signaling and will not carry NAS level signaling. RRC level signaling deals with paging, configuration of the nodes for using radio-resources, mobility related procedures, measurements, QoS management and control etc. The RRC connection has to be maintained even when there is no explicit data transfer, since it is used as a paging channel.

Other than RRC messages, system information messages are also transmitted. The system information (unlike Wimax and like UMTS) consists of several blocks; of this, the master block is mandatory for the UT to read; reading other blocks is dependent on the UT state.

All communication between the RNC and user terminal happens through one or more radio-bearers. Radio-bearers are roughly equivalent to the combination of MAC level connections and service flows in WiMAX., however they are divided into signaling radio bearers (SRBs) and data radio bearers (DRBs), each of which are separately configurable. Flows at the layer 2 level are multiplexed onto the appropriate radio-bearers.

Signaling Radio-bearers have functions analogous to the ISF in Wimax in that they are designed to carry RRC and NAS messages as follows

1. SRB0 for RRC messages only
2. SRB1 for RRC and piggybacked NAS messages
3. SRB2 for NAS messages after security procedures have been completed.

Other than, SRBs and DRBs can be both created, modified and deleted dynamically.

5.2 QoS support

TBD

5.3 Handovers and Mobility

The handover and mobility support in LTE and Wimax are quite different. While Wimax is more diverse in types of handover supported, LTE is designed to allow handover between multiple different radio-access technologies. Also, LTE, as of now, does not support any user terminal based handover; this makes handover very much simpler, since it is always triggered by the eNodeB, through an RRC reconfiguration command. We shall spend a little time describing LTE handover, after which we shall outline the differences.

5.3.1 Measurements for the purpose of handover

LTE eNodeBs issue commands to the user terminals to initiate measurements for the purpose of handovers (similar to the commands in Wimax DCD messages). The trigger conditions are similar to those of Wimax, with some slight variations; for example, all measurements are absolute comparisons against provided threshold values (relative comparisons against the neighbour, as in Wimax triggering modes 0x01 to 0x04 are not supported), but compound events are supported. The only possible response, obviously, is to send an updated measurement reported to the eNodeB.

The (implicit) topology of the LTE network is provided through a set of measurement objects, which identify, for multiple RATs, the list of cells which are to be covered through measurements. Additionally, discovered cells may also be reported by the user terminal. The eNodeB can also blacklist some cells, so that they are not measured or reported on.

Measurements are captured by the physical layer and reported to the RRC, which filters them using a sliding window filtering algorithm. The discount parameter is, of course, configured by the eNodeB.

5.3.2 The handover process

The handover process in LTE is always initiated by the eNodeB, by transmission of an RRC reconfiguration command to the user terminal. The reconfiguration command can, in one single package, contain the new cell-identity, the new radio link configuration, lower layer security information as well as the required SRB/DRB modification information. However, most of these parameters are provided optionally; inclusion/exclusion can map to the handover optimization TLVs available in Wimax.

6 References