The LTE Radio Interface – Key Characteristics and Performance

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Abstract—Mobile broadband usage is taking off, demanding improved services and increased capacity of mobile networks. To meet these requirements, 3GPP has defined LTE (the 3GPP Long Term Evolution). This paper presents some key characteristics of the LTE radio interface, including physical layer and radio resource management functions, and evaluates their impact on system performance. As compared to a reference system with more basic characteristics, represented by Mobile WiMAX, results point to a combined gain in spectrum efficiency of 60% in downlink and 100% in uplink. Cell-edge bitrate gains are about 100% in both downlink and uplink. A closer analysis of the individual system characteristics indicates that these performance differences are due to rather uniform contributions from a set of distinctive features.

Index Terms—LTE, Performance, WiMAX

I. INTRODUCTION

Usage of mobile broadband services, supported by the introduction of High Speed Packet Access (HSPA), is taking off. To meet the future increased demand for such services, corresponding improvements in the supply of services are required, including higher bit rates, lower delays, and higher capacity. This is the target of 3GPP’s two radio access networks HSPA and LTE [1], of which the latter is the focus of this paper. LTE brings unprecedented performance. Examples include peak data rates exceeding 300Mbps, delays below 10ms, and manifold spectrum efficiency gains over early 3G system releases. Further, LTE can be deployed in new and existing frequency bands, has a flat architecture with few nodes, and facilitates simple operation and maintenance. While targeting a smooth evolution from legacy 3GPP and 3GPP2 systems, LTE also constitutes a major step towards IMT-Advanced systems. In fact, LTE includes many of the features originally considered for future fourth generation system.

General LTE concept descriptions are available in [1]. In this paper, the focus is on key characteristics of the LTE radio interface. A set of such key characteristics are both qualitatively discussed and quantitatively evaluated in terms of downlink and uplink user data rates and spectrum efficiency generated by means of system level simulations. For reference, the LTE characteristics are compared to more conventional solutions. These are represented by corresponding functionalities in Mobile WiMAX with Partial Usage of Sub-Channels (PUSC) [2].

The paper is outlined as follows: After an introduction to the basic structure of the LTE radio interface in Section II, Section III provides a qualitative discussion of distinctive features of the evaluated system concepts, and their impact on performance. Models and assumptions are summarized in Section IV, followed by numerical results in Section V. Finally, a summary is provided in Section VI.

II. AN OVERVIEW OF THE LTE RADIO INTERFACE

Comprehensive descriptions of the LTE radio interface are available in [1]. In short, LTE is based on Orthogonal Frequency Domain Multiplexing (OFDM). The numerology includes a subcarrier spacing of 15kHz, support for bandwidths up to 20MHz, and resource allocation granularity of 180kHz x 1ms (a so-called resource block pair). In the uplink, a pre-coder is used to limit peak-to-average power ratios, and thereby reduce terminal complexity. Based on channel quality, modulation (up to 64QAM) and channel coding rates are dynamically selected. Both FDD, TDD, and half duplex FDD are supported. A variety of antenna concepts targeting different scenarios is included: transmit diversity for improved robustness of control channels, beamforming for improved channel quality in general, and multi-stream (MIMO) transmission for improved data rates in scenarios with good channel quality. On the MAC layer, dynamic scheduling is done on a resource block pair basis, based on QoS parameters and channel quality. Retransmissions are handled with two loops, a fast inner loop taking care of most errors complemented with a very robust outer loop for residual errors.

III. KEY LTE CHARACTERISTICS

Some of the more fundamental features discussed in the previous section are not unique to LTE. E.g. OFDM, multi-antenna transmission, and adaptive modulation and coding are standard techniques used by many systems. On a more detailed level however, LTE distinguishes itself by using more sophisticated solutions than other systems. A list of such characteristics is presented in Table I. For reference, the corresponding solutions used in more basic systems are also listed. This is represented by Mobile WiMAX Wave 2. It should be noted that there are several other features differing between these systems which are not listed, e.g. control signaling robustness, higher layer overhead, and mobility aspects.
### TABLE I
LTE KEY CHARACTERISTICS

<table>
<thead>
<tr>
<th>Function (slogan used in Fig. 1-2)</th>
<th>LTE</th>
<th>Mobile WiMAX wave 2</th>
<th>Performance impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple access (MA)</td>
<td>OFDM in 2DL, DFT-spread OFDM in UL</td>
<td>OFDM in DL and UL</td>
<td>DFT-spread OFDM reduces the peak-to-average power ratio and reduces terminal complexity, requires one-tap equalizer in base station receiver</td>
</tr>
<tr>
<td>Uplink power control (PC)</td>
<td>Fractional pathloss compensation</td>
<td>Full pathloss compensation</td>
<td>Fractional pathloss compensation enables flexible trade off between average and cell-edge data rates</td>
</tr>
<tr>
<td>Scheduling (Scheduling)</td>
<td>Channel dependent in time and frequency domain</td>
<td>Channel dependent in time domain</td>
<td>Access to the frequency domain yields larger scheduling gains</td>
</tr>
<tr>
<td>MIMO scheme (MIMO)</td>
<td>Horizontal encoding (multiple codewords), closed loop with precoding</td>
<td>Vertical encoding (single codeword)</td>
<td>Horizontal encoding enables per-stream link adaptation and successive interference cancellation (SIC) receivers</td>
</tr>
<tr>
<td>Modulation and coding scheme granularity (MCS)</td>
<td>Fine granularity (1-2dB apart)</td>
<td>Coarse granularity (2-3dB apart)</td>
<td>Finer granularity enables better link adaptation precision</td>
</tr>
<tr>
<td>Hybrid ARQ II (HARQ)</td>
<td>Incremental redundancy</td>
<td>Chase combining</td>
<td>Incremental redundancy is more efficient (lower SNR required for given error rate)</td>
</tr>
<tr>
<td>Frame duration (CQI delay)</td>
<td>1ms subframes</td>
<td>5ms frames</td>
<td>Shorter subframes yield lower user plane delay and reduced channel quality feedback delays</td>
</tr>
<tr>
<td>Overhead / control channel efficiency (OH / CCH eff)</td>
<td>Relatively low OH (while control channels are robust)</td>
<td>Relatively high OH</td>
<td>Lower overhead improves performance</td>
</tr>
</tbody>
</table>

### IV. MODELS AND ASSUMPTIONS

Models and assumptions are aligned with the NGMN recommendations in [3]. Table II contains a brief summary. The evaluation methodology is based on time-dynamic, multi-cell system simulations.

### V. NUMERICAL RESULTS

This section presents downlink and uplink user throughput and spectrum efficiency for a selection of system configurations and scenarios. More specifically, the following subsections cover (A) baseline configurations with 2x2 and 1x2 antenna configurations, (B) more advanced multi-antenna configurations, and (C) results for file transfer (non-full buffer) traffic models.

#### A. LTE and Mobile WiMAX – Baseline Scenario

Downlink user throughput and spectrum efficiency figures for LTE FDD, LTE TDD, and Mobile WiMAX are summarized in Fig. 1. Note that in this special case, as there are 10 full-buffer users per sector in average, and the spectrum allocation is 10MHz, the spectrum efficiency, measured in bps/Hz/sector, and the average user throughput, measured in Mbps, are the same. For the TDD systems, the spectrum efficiency is calculated by down-scaling the denominator (system bandwidth) with the relative time utilization in the direction in question (measured in data symbols). Distributions of user throughput normalized with spectrum allocation and TDD utilization are also presented.

It is seen that LTE is some 60% better than Mobile WiMAX in the average metrics, and about a factor two better in cell-edge performance. The reasons for these differences are a combination of the distinctive features presented in Table I.
The individual impact of each such feature has been assessed by, in the simulations, replacing the LTE functionality with the corresponding WiMAX functionality. The result is shown in the lower bar graph in Fig. 1. The percentage figure to the left represents the individual feature impact, and the percentage figure to the right the accumulated impact of the features combined. It is seen that the total difference is not due to a single distinctive feature, but rather a combination of distinctive features, headed by frequency domain scheduling, faster channel quality feedback, and control channel efficiency. Note also that when all distinctive features are replaced, the performance is the same, confirming that these features are indeed the reason for the overall difference in performance. A similar analysis can be made for the cell-edge metric.

Similar results for the uplink are summarized in Fig. 2. In this direction, it is seen that LTE is more than a factor two better than Mobile WiMAX in both average and cell-edge metrics. Also here, the distinctive features jointly make up the
total performance difference, lead by control channel efficiency (OH), faster channel quality feedback, and more flexible power control.

The small difference between LTE FDD and TDD depends on the TDD guard period and differences in channel quality feedback delays.

B. Results with Additional Antenna Concepts

In this section results with more advanced antenna concepts are presented. Downlink results are summarized in Fig. 3. It is seen that both average and cell-edge performance are improved by using 4x2 and 4x4 MIMO solutions.

For the uplink, results with four receive antennas are presented in Fig. 4. In addition to receive diversity results, results for multi-user MIMO, with 2 users multiplexed, are shown. A significant performance increase is achieved already using 4-branch receive diversity. The additional gain provided by MU-MIMO is smaller. With two receive antennas the MU-MIMO gains are even smaller.

C. Results for File Transfer Traffic Models

In addition to the full buffer traffic model, for LTE, evaluations with a file transfer traffic model have also been performed. For simplicity, a fixed file size of 100KB is assumed. Although simple, this model captures a number of realistic phenomena not covered by the full buffer model. These include the ‘equal buffer’ effect of users with low data rates dominating the link usage, and the effect of interference variations caused by transmitters switching on and off. The file transfer model also enables the possibility to study achievable user data rates under varying load conditions.

A number of traffic load levels, realized by different session arrival intensities, are evaluated and user bitrates are logged. The user bitrate is measured as the file size divided by the time between arrival in the system and successful reception. Queuing delays are hence included. The baseline system configurations are assumed (2x2 DL and 1x2 UL).

Results in the form of 5th, 50th, and 95th percentile user bit-rates as a function of served traffic per sector are presented in Fig. 5. It is seen that very high user bitrates are achieved. At ‘low’ load (1-2Mbps/sector), the cell edge bitrate exceeds 20Mbps in downlink, and is almost 10Mbps in UL. Average values are about a factor two higher, and the 95th percentile values are not far from the theoretical peak data rates (72Mbps in DL and 26Mbps in UL with the overhead assumptions made). Further, the capacity, here measured as the maximum sector throughput for a certain 5th percentile bitrate (e.g. 1Mbps), is not very much lower than in the full buffer case.
VI. SUMMARY

The results presented indicate that in normalized metrics LTE, with its more sophisticated radio interface, outperforms the more basic Mobile WiMAX Wave 2 in both downlink and uplink and for both FDD and TDD operation. In the downlink, LTE is about 60% better in spectrum efficiency and average user throughput, and 100% better in cell-edge user throughput. In the uplink, LTE is 100% better in both average and cell-edge performance. Utilizing the full LTE potential (4x4 MIMO, 20MHz carriers, FDD), the differences are even greater. The large gains for LTE cannot be attributed to a single feature, but are rather the effect of a number of distinctive characteristics, each contributing to the overall gain.

With non-full buffer traffic, very high user bitrates are achieved for LTE. In low to moderate load scenarios, bitrates of tens of Mbps are achievable at the cell-edge, and theoretical peak data rates are approached closer to the base station.

In general, absolute performance values depend largely on the scenario, models, and assumptions used, here aligned with the NGMN recommendations. Although relevant and well-designed, different results are achieved in other scenarios and under different assumptions. For example, refined base station antenna models, based on realistic antenna patterns and modeling vertical antenna diagrams, typically yield improved absolute spectrum efficiency and user throughput values [4].

REFERENCES