Initial field performance measurements of LTE

Researchers have measured the performance of LTE in the field using different drive routes and radio channel environments. Among other things, they measured different bandwidths, different antenna configurations and layer-1, UDP and TCP throughput using two kinds of terminals.

In January 2008, 3GPP confirmed that the technology specifications for the LTE Terrestrial Radio Access Network had been approved and were under Change Control, which means they will be included in the forthcoming 3GPP Release 8.1 At Mobile World Congress 2008, in Barcelona, major CDMA and WCDMA operators, such as NTT DoCoMo, Verizon Wireless, Vodafone and China Mobile, confirmed their commitment to LTE as the next-generation mobile network. And wireless industry leaders have reached an agreement concerning a framework for licensing technology IPR.

This article describes some of the field-performance measurements made using different drive routes and radio channel environments while traveling at velocities of up to 120km/h and at distances of up to 4km. The trials include measurements of both 10MHz and 20MHz bandwidths and of different antenna configurations up to 4×4 MIMO. The article also presents the layer-1, UDP and TCP throughput using two different kinds of terminals: a large terminal (the test bed, built on DSP technology) and a prototype handheld terminal. Please note that the performance figures are taken from the test-bed results; the actual performance of commercial products might differ somewhat.

**LTE**

The LTE standard is being developed in two 3GPP work items: The LTE work item targets the evolution of the radio network; and the SAE (System Architecture Evolution) work item targets the evolution of the packet core network. In contrast to previous standards, the LTE standard solely specifies a packet-switched (PS) domain for LTE and SAE. Output from the work items is embodied in the Evolved UTRAN (E-UTRAN) and the Evolved Packet Core (EPC) standards. Together, they form the Evolved Packet System (Figure 1).

The E-UTRAN standard employs orthogonal frequency-division multiplexing (OFDM) technology for downlink operation and single-carrier frequency-division multiple access (SC-FDMA) technology for uplink operation. This approach yields excellent flexibility in terms of deploying and allocating spectrum from 1.4MHz up to 20MHz. In addition, the E-UTRAN standard supports FDD (frequency-division duplex) as well as TDD (time-division duplex) modes of operation.

The basic LTE downlink physical resource can be seen as a time-frequency grid (Figure 2), where each resource element corresponds to one OFDM subcarrier during one OFDM symbol interval. Downlink subcarrier spacing has been set at 15kHz.

LTE uplink transmission is based on SC-FDMA with dynamic bandwidth. The single-carrier property of the uplink, which limits transmission to a contin-
Subcarrier spacing = 15 kHz

One resource element

One OFDM symbol

Frequency

Subcarrier spacing = 15 kHz

Ericsson LTE test bed

The hardware architecture of Ericsson’s LTE test bed is a one-sector, one-cell system designed for early testing and proof-of-concept. Some updates have been made to the hardware since 2006, but it is essentially the same flexible, high-performance platform described in LTE test bed. It supports

- a variety of configurations, antenna setups, and system bandwidths; and
- measurements of layer-1, layer-2 and application-level performance.

The baseband software is based on a common platform, but different versions of the code are used for different hardware configurations in order to match the current antenna configuration. Test bed development has taken place in parallel with the 3GPP standardization process. Therefore, the LTE test bed does not exactly mirror the most recent 3GPP LTE specification. The MIMO scheme in the test bed, for example, employs selective per-antenna rate control (S-PARC), which means streams can be individually encoded and modulated and a single data stream is always mapped to a single transmit antenna.

In addition to measurements made using the LTE test-bed hardware, this article includes measurements performed with a prototype handheld LTE device developed by Ericsson Mobile Platforms (EMP) and shown at Mobile World Congress 2008 in Barcelona (Figure 3). The terminal, which is compatible with the base station, has been used

- to perform modem use cases with a laptop;
- to demonstrate multimedia telephony (for example, VoIP);
- to demonstrate video telephony;
- to perform file transfers;
- to stream video applications; and
- to test multiple terminals simultaneously.

Experimental

The results were obtained using the test bed in the laboratory and in extensive outdoor field tests.

Fading emulators and additive white Gaussian noise (AWGN) sources were used in the lab to measure the performance of different channel profiles at different signal-to-noise ratios (SNR). For the field trials, an LTE test site was installed on the roof at Ericsson’s headquarters in Stockholm (Figure 4). Commercially available antennas for the 2.6 GHz band were used at the base station and in the terminal. To evaluate the use of spatially separated and dual-polarized antennas, the testers used different antenna setups and benchmarked them against each other for different MIMO configurations.

The test-bed terminal was installed in a measurement van with antennas mounted on the roof (Figure 5). A GPS receiver was also used to make it possible to associate logged performance with the position of the terminal. The field tests were performed in two sectors that represent different instal-
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FIGURE 3 “Berta” – Ericsson’s prototype handheld LTE device.

FIGURE 4 Installation of the base station antenna.

The first sector is quite sparsely settled and dominated by low-rise buildings (compared to the site installation height) – line-of-sight (LOS) conditions were thus fairly common. The second sector is more dense and building heights are comparable to the site installation – LOS conditions were thus quite rare.

The majority of the field tests were performed within a radius of 1km from the test site. The tests also included distances of more than 4km. During most parts of the field tests, the speed of the terminal was between 5 and 40km/h. Some of the tests were conducted while driving on a freeway at speeds of more than 100km/h.

Measurements

Lab results

Figure 6 contrasts the layer-1 throughput with SNR of different antenna configurations. The measurements, made with 10MHz bandwidth and the Extended Vehicular A (EVA) 3km/h channel model, were complemented with an emulated cross-polar discrimination (XPD) of 10dB, which simulates the use of dual-polarized antennas. As anticipated, the 1×4 setup outperforms the 1×2 setup, especially when SNR is low. Compared to the 1×2 setup, the 2×2 setup yields gains of approximately 10 to 15dB and up. By contrast, the 2×4 setup, yields multi-stream gains of around 5dB. The gain with four streams compared to two is seen from 20dB and up.

With this specific channel model, the peak throughput of the 4×4 setup yields a gain of approximately 150 percent compared to the 1×2 setup. Other channel models yield different gains – Figure 7, for example, shows the gain that can be obtained from using an ideal 4×4 AWGN MIMO channel.

To evaluate application level performance, measurements were taken using UDP and TCP traffic over a 2×2 20MHz MIMO Pedestrian B 3km/h (PB3) channel. As can be seen in Figure 8, the difference in performance between UDP and TCP is very small. UDP is a best-effort transmission technique without acknowledgements from the terminal to the base station. It is thus insensitive to uplink performance and IP-related issues, such as system buffer sizes. TCP, on the other hand, transmits
The results indicate that the test system has a well-tuned and reliable uplink.

**Field results**

In good radio conditions, the system achieved the theoretical maximum throughput over the downlink of a 2×2 system using link adaptation and 20 MHz bandwidth: 170 Mbps. Using four transmit streams (the maximum number supported in the LTE standard), four receive antennas (4×4 MIMO) and 10 MHz bandwidth, the measured peak rates exceeded 130 Mbps. This translates into approximately 260 Mbps, given the maximum bandwidth of 20 MHz, which is more than three times the peak throughput that can be achieved from a basic 1×2 setup.

**Figure 9** shows the cumulative distribution functions (CDF) for different antenna configurations along a drive route where vehicle velocity was between 5 and 40 km/h. The measurements show that adding more transmit and receive antennas improves performance. **Table 1** compares the relative gains to a basic 1×2 setup along a given drive route. The MIMO-related gains are strongly dependent on radio channel conditions and should therefore solely be seen as an example of what can be achieved.

The addition of more transmit streams (up to four) increases peak throughput by approximately 60 percent, whereas the mean throughput increased by eight percent to 25 percent compared to the 2×4 setup. In conclusion, besides increasing peak data rates, we see that multi-stream transmission improves the mean and 10th percentile data rates.

**Figure 10** and **11** show performance along a drive route using 10 MHz bandwidth for 4×4 and 2×2 MIMO setups. Good throughput was achieved along the entire route. In some areas the peak rates were very high. The 4×4 setup performed better than the 2×2 setup except in line-of-sight conditions where performance was similar.

The lab measurements (Figure 11) assessed the TCP and layer-1 bit rates available for applications using 20 MHz bandwidth. The difference between layer-1 bit rates and corresponding TCP bit rates can be attributed to protocol overhead. The layer-1 bit rate (no protocol overhead) is available to higher-level applications.

The TCP bit rate was more than 40 Mbps at least 50 percent of the time and more than 100 Mbps at least 10 percent of the time.

The impact of velocity on performance was evaluated on a freeway. Given good radio conditions, a bit rate of more than 100 Mbps was obtained while traveling at more than 100 km/h and using 20 MHz bandwidth. Under the same conditions, but at a distance of more than 4 km from the base station, throughput was 40 Mbps or greater.

Field measurements using the prototype handheld terminal were conducted in Nuremberg, Germany.

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**Table 1** Example of relative gain compared to 1×2 antenna setup.

<table>
<thead>
<tr>
<th>Throughput gain relative 1 x 2 setup</th>
<th>10th percentile</th>
<th>Mean</th>
<th>90th percentile</th>
</tr>
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<tbody>
<tr>
<td>1 x 4</td>
<td>+ 15 %</td>
<td>+ 12 %</td>
<td>+ 1 %</td>
</tr>
<tr>
<td>2 x 2</td>
<td>+ 27 %</td>
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<tr>
<td>4 x 4</td>
<td>+ 104 %</td>
<td>+ 108 %</td>
<td>+ 100 %</td>
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</table>
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Commercially available antennas were installed on the fourth floor at Ericsson’s premises. The frequency band was 2.6 GHz; bandwidth was 20 MHz.

In a static measurement made close to the base station (Point A), the maximum layer-1 bit rate over the downlink was 25 Mbps. This is also the maximum throughput of the prototype terminal in this configuration when connected via cable. UDP throughput over the downlink was close to 23 Mbps. As the terminal moved away from the base station (Point B), the maximum layer-1 data rate remained steady at 25 Mbps, whereas UDP throughput fell slightly to just above 20 Mbps. Driving with the terminal at close to 30 km/h, the layer-1 data throughput over the downlink was around 22 Mbps; the UDP data rate was around 18 Mbps.

To further demonstrate the strength of the prototype, three additional terminals were placed in radio conditions that varied from high to considerably low SNR. Despite a variance in SNR of more than 20 dB, all three terminals reached a throughput of about 14 Mbps. Keeping in mind that the terminal is still an early prototype, these performance figures are most promising.

Summary and future perspectives
Measurements made in the lab and extensive field trials show that LTE performs well in both the physical and application layers. Multi-stream MIMO yields good gains in realistic environments, improving peak rates as well as the mean and 10th percentile throughput. A small, prototype handheld LTE terminal has been used, among other things, to stream video from an LTE test-bed base station and to illustrate that LTE is quickly becoming a mature technology.

Work is also under way to standardize the next releases of 3GPP to ensure that future end-user and operator requirements are met. The International Telecommunication Union (ITU) is defining the requirements for IMT Advanced, sometimes also referred to as “4G.” Some of the requirements being discussed are bit rates of up to 1 Gbps in the downlink, more than 500 Mbps in the uplink, and a scalable bandwidth of up to 100 MHz. Other requirements...
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The 3GPP has begun working on LTE Advanced, which is scheduled for inclusion in 3GPP Release 10. LTE Advanced should fulfill, but not be limited to, the IMT Advanced requirements. The 3GPP view is that LTE Advanced should

- aim for NGMN (next-generation mobile network) system performance. The NGMN intends to complement and support the work within standardization bodies by providing a coherent view of what the operator community will require in the decade beyond 2010;
- fulfill 3GPP compatibility requirements – that is, it should allow LTE Release 8 terminals in LTE Release 10 networks and vice versa; and
- support smooth migration from LTE Release 8.

In addition, the 3GPP is studying extended multi-antenna deployments as well as ways of lowering terminal and network power consumption.

References

1. www.lstiforum.org
5. 3GPP spec. 36.101, ver. 8.1.0, Annex B
6. 3GPP spec. 25.101, ver. 8.2.0, Annex B