Field trials of LTE with 4×4 MIMO

Multi-antenna reception and transmission is a key enabler of the high performance offered by LTE.
downlink transmission was set at 10MHz.
The test bed incorporated the basic LTE frequency division duplex (FDD) principles and had similar parameters.\textsuperscript{4-5} The relevant multi-antenna techniques were aligned with 3GPP Rel-8, and therefore it was anticipated that the measured results would be representative of the relative throughput gains achievable for LTE with multiple transmit and receive antennas in the scenarios considered.\textsuperscript{2}

Table 2 shows some basic parameters of the test bed. Given that the test bed was a prototype, the absolute performance is not necessarily representative of commercial products.

The results were obtained using LTE transmission mode 4. The codebooks defined in the standard were used for frequency-selective precoding.\textsuperscript{2} Nine precoders are selected over the 10MHz bandwidth, each valid for a subset of the band. The total downlink transmit power was normalized to be independent of transmission rank and number of transmit antennas.

Field trials
An important goal of the field trials was to measure the relative performance of different antenna setups at the eNB. A similar campaign for MIMO high-speed packet access (MIMO-HSPA) was described in MIMO-HSPA Test Bed Performance Measurements.\textsuperscript{6}

The field trials were conducted in a business district in northern Stockholm, Sweden. The UE was driven along two separate routes in two sectors (Sector 1 and Sector 2) at speeds ranging from 5-30km/h. Figure 1 shows an aerial photograph of the area with drive routes drawn in. Sector 1 is suburban with flat, open areas and relatively low buildings. Sector 2 is urban and occupied by five- to nine-floor office buildings on undulating terrain. In each sector, the maximum distance between the eNB and UE was around 720m. Also, two power settings were used in each:
\begin{itemize}
\item 34dBm and 38dBm in Sector 1, and
\item 34dBm and 24dBm in Sector 2.
\end{itemize}

Antenna system configuration
The eNB site installation was designed to imitate a conventional macro-cellular site with antennas slightly above rooftop height. The eNB antennas were prototypes developed by Ericsson specifically for the measurement campaign. Figure 1 shows the eNB antenna arrangement in each sector.

Each eNB antenna enclosure housed four linearly arranged columns with a horizontal spacing of 0.77 (~8cm). Each column consisted of a dual-polarized (+45 and -45 degrees), co-localized antenna pair. In total, there were eight antenna ports per enclosure. Each sector had multiple separate antenna enclosures mounted on horizontal bars, enabling reconfigurable inter-antenna spacing ranging from 8cm to 3m. The eNB was equipped with a dynamic calibration system that ensured coherent transmission from the antennas.

The UE antennas were mounted on the roof of a van, arranged in a square pattern with 20cm inter-antenna spacing. Two types of antennas were used: horizontally polarized antennas from SATIMO, and vertically polarized antennas from Kathrein. Both types...
were omnidirectional in the horizontal plane.

**Results**

*Power gain versus multistream gain*

Below we compare two categories of antenna setups: those intended to create a channel that is correlated at the transmit side, and those intended to create a channel that is uncorrelated at the transmit side. The latter category is typically well suited for multi-stream transmission (spatial multiplexing) to users with good channel conditions—that is, to users near the cell center with a high signal-to-noise ratio (SNR). The former is best suited for beamforming toward users with bad channel conditions—that is, to users near the cell edge with a low SNR.

The correlation level at the transmit side depends not only on the antenna setup but also on the propagation environment. However, for simplicity, this article denotes the two archetypical setup types: correlated and uncorrelated.

The correlated configuration was obtained by having closely spaced transmit antennas of equal polarization. In the 4×4 MIMO example, the correlated configuration is denoted with [a] in the figure; in the 4×2 MIMO example, with [l]. Four co-polarized columns were used in a single antenna enclosure, resulting in an inter-element distance of $0.7\lambda$.

The uncorrelated configuration was obtained using two dual-polarized columns with wide spacing. In the 4×4 MIMO example, the uncorrelated configuration is denoted with [c] in the figure; in the 4×2 MIMO example, with [k]. The inter-element distance between the dual-polarized pairs was approximately $25\lambda$.

In all four examples described above, the UE antenna configuration comprised antennas of both vertical and horizontal polarization—two of each kind for the four-antenna UE setup, and one of each kind for the two-antenna UE setup.

**Figure 2** shows the performance of the correlated and uncorrelated benchmark configurations for drive tests in Sector 2 with the low power setting (top left), Sector 2 with the high power setting (top right), and in Sector 1 with the low power setting (bottom left). For a

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrier frequency</td>
<td>2.6GHz</td>
</tr>
<tr>
<td>System bandwidth</td>
<td>10MHz, UE always scheduled over entire bandwidth</td>
</tr>
<tr>
<td>Link adaptation, closed loop operation (3GPP mode 4)</td>
<td>Rank, PMI and channel-quality indicator (CQI) feedback on millisecond timescale. Time between channel measurement and transmission of the resulting transport format is around 5ms</td>
</tr>
<tr>
<td>Hybrid automatic repeat request (HARQ)</td>
<td>HARQ with chase combining</td>
</tr>
<tr>
<td>Receiver</td>
<td>Minimum mean square error (MMSE) receiver</td>
</tr>
<tr>
<td>LTE duplex mode</td>
<td>FDD</td>
</tr>
<tr>
<td>Number of antennas (downlink)</td>
<td>eNB: 1, 2 or 4. UE: 2 or 4</td>
</tr>
</tbody>
</table>
given number of receive antennas in the UE, CDFs corresponding to each benchmark eNB configuration clearly intersect for all two- and some four-antenna UE cases. None of the benchmark configurations consistently performed best during all parts of any given route. The uncorrelated setup performed best above the intersection point, in the high throughput region, while the correlated setup performed best below the intersection point in the low throughput region. The level of the intersection point along the vertical axis gives the relative proportion of how often one setup outperformed another along a drive route. The intersection point is dependent on the scenario.

In general, CDFs that correspond to test drives with the low power setting intersect at higher points than those for test drives with the high power setting. This may be attributed to the fact that, given single-layer transmission, increased received power gives UEs operating with low receive power and a low SNR a more significant increase in throughput than UEs operating with high receive power and a high SNR. The correlated setup gives a larger power gain than the uncorrelated setup. In the higher power region, it is usually much more beneficial to transmit multiple layers, and the uncorrelated setup creates channels that better support this kind of transmission. For similar reasons, the drive routes in the more challenging Sector 2 produced curves that intersect at higher points than those of the more open Sector 1.

The intersection point for CDFs that correspond to the UE configuration with four antennas was lower than those that correspond to the UE configuration with two antennas. In a relative sense, due to its lesser ability to improve SNR by coherently combining the signals received by multiple antennas, the two-antenna UE setup benefits more from the increase in received power provided by the correlated setup. By contrast, the four-antenna UE benefits more from the uncorrelated setup, which improves the ability of the channel to support multiple layers.

Increasing the number of receive antennas always improves performance. For a given number of receive antennas, multi-antenna transmission using the correlated benchmark eNB setup outperforms single-antenna transmission (single input, multiple output or SIMO) in every case. In most cases, the uncorrelated setup shows a gain over SIMO, and in some cases it dramatically improves throughput. Due to the larger reference signal overhead in multi-antenna transmission, SIMO occasionally outperforms the uncorrelated setup.

Figure 2 (bottom right) shows results in Sector 2 for the low power setting but includes setups with two transmit antennas. Clearly, the closely spaced co-polarized setup [j] performs better than the dual-polarized setup [i] for users with the least favorable channel conditions. On the other hand, the dual-polarized setup performs better for users with better channel conditions. The results also suggest that a four-antenna eNB setup with two closely spaced dual-polarized pairs [v] captures the benefits of both the two-antenna eNB setups shown. One other visible benefit of that setup for...
a four-antenna UE is the ability to transmit more than two layers when channel conditions allow it.

Polarization-matching aspects
The UE antenna configurations described thus far were composed of purely vertically and horizontally polarized antennas. Such configurations are well matched to eNB antenna configurations and transmission modes that rely on polarization diversity – for example, multi-stream transmission with dual-polarized antennas. Note, however, that perfectly orthogonal polarizations are hard to obtain in practical UE implementations. The ability to support multi-stream transmission using polarization diversity diminishes the more similar the UE antennas are to each other in polarization. To illustrate this principle, tests were performed for both 4×4 and 2×2 MIMO using exclusively vertically polarized antennas in the UE.

Figure 3 (left) shows the resulting CDFs. In terms of throughput, performance decreases in the high-throughput region with an unmatched UE antenna configuration, due to the reduced ability to sustain multi-layer transmission. This is also evident from the bar charts in Figure 3 (right), which show the transmission-rank proportion. The CDFs also suggest that the opposite holds true in the low-throughput region, where single-layer transmission dominates. This effect may be ascribed to the ability of an eNB with dual-polarized antennas to match the effective polarization of the transmission through proper choice of precoder. The polarization can be matched when the UE has antennas with parallel polarization, but not when the polarization is mixed as in the orthogonal case. The intersection point for the 4×4 setups is different from that of the 2×2 setups. The gain from matching polarization is mainly one of SNR; the CDFs for the 2×2 setups intersect at a higher point than those for the 4×4 setups, which is in line with the results reported above.

LTE – mobile broadband now and tomorrow
The first commercial LTE networks are currently being launched. Multi-antenna technology is thus already a vital component in the evolution of mobile broadband. And its importance will continue to increase as user traffic grows and puts greater demands on network capacity. Two use cases exemplify the potential of LTE multi-antenna technology to meet these increasing capacity demands:

- a user close to the cell center, limited by cell capacity and peak throughput; and
- a user close to the cell edge, limited by network coverage.

Figure 4 (left) shows the first use case. Those parts of the Sector 2 measurement route that primarily support the transmission of multiple streams were selected with the transmit power set to high. A typical 2×2 MIMO configuration (which represents the first generation of multi-antenna-capable LTE products) is presented together with a 4×4 MIMO system that uses the uncorrelated transmit antenna setup.

The second use case is illustrated in Figure 4 (right), comprising the parts of Sector 2 that are closer to the cell edge, with the transmit power set to low. A 4×4 MIMO setup using the correlated transmit antenna configuration is presented together with the reference used in the first case.

Figure 5 shows the selected parts of the drive route in Sector 2. Note that 3GPP LTE Rel-8 supports up to twice the frequency bandwidth used in the measurements. For the cell center case, a 50 percent increase in median throughput was measured; for the cell edge case, the median throughput was more than doubled. These examples clearly illustrate the potential of the multi-antenna technologies in LTE Rel-8 to appease growing demands on network capacity.
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Bo Hagerman received an MSc EE, Lic. Tech. EE and PhD in Radio Communication Systems from the Royal Institute of Technology, Stockholm, Sweden in 1987, 1993 and 1995, respectively. From 1987 to 1990, he was a member of the technical staff in the Ericsson Radio Systems Research and Development department, where he worked in the area of signal processing with applications to GSM receivers. He joined the Radio Access Technologies Research department at Ericsson Research, Stockholm in 1995, where he is currently a Senior Specialist in the area of Advanced Antenna Systems, working with research on multiple antenna systems and heterogeneous deployments in cellular networks.

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References