Data Rate Performance Gains in UMTS Evolution to LTE at the Cellular Level

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Abstract— Mobile communications technologies are aiming at responding to the growing demand for higher connectivity. Performance of recent 3G and 4G systems, UMTS/HSPA+ and LTE, is evaluated regarding the number of users. LTE measurements were taken and system implementation features were analysed. A simulator for UMTS and LTE was built based on the results, considering both single- and multi-user scenarios. DL average throughputs of 40 Mbps and 69 Mbps, for UMTS and LTE, are obtained for single-user. Interference coordination and additionally higher order MIMO in LTE increase data rates by factors up to 1.39 and 2.31. Rising average throughput ratio between UMTS and LTE is proved to follow a logarithmic law with the number of users in DL. In UL, average data rates of 11 Mbps and 57 Mbps, for UMTS and LTE, are observed for one user. Interference coordination provides gains up to a factor of 1.5. Approximately stable UMTS to LTE gains are obtained for more than 5 users. Higher data rate variations were measured across the cell in LTE compared to UMTS, for UL and DL. Apart from very particular scenarios, LTE provides for the best UL and DL coverage in the typical multi-user scenarios studied, across all environments.

Keywords: LTE, UMTS/HSPA+, Capacity, Throughput, Coverage, QoS

I. INTRODUCTION

Mobile communications have known, in recent years, great technological developments. The demand for an always on connection to Web services and personal communications services has supported the development of broadband connection services. Particularly, for cellular systems in Europe, this is directly reflected in a huge appetite for Universal Mobile Communications Systems (UMTS) in its latest High Speed Packet Access Evolved (HSPA+) version and Long Term Evolution (LTE). However, as today’s data services are following a growth curve similar to the one seen for wire line data, average revenue per user is falling almost as rapidly, Figure 1. Further, growing traffic placed on 3G networks is bringing significant network congestion in urban areas and many operators are reporting that a significant portion of their cell sites in urban areas are already running at over capacity, despite having enabled all their UMTS carriers. Once an operator has deployed all its UMTS carriers, he is faced with the need to provide additional capacity, and can only continue doing so by adding more cells sites or by means of an LTE network overlay. Many operators have been lead to deploy LTE to meet the needs of the wireless broadband mass market, allowing for bandwidth-hungry applications to be supported cost effectively with the equivalent or better user experience. Additionally, LTE is expected to deliver new mobile services, and new revenue, that will excite users and help operators drive competitive advantage.

In preparing the networks to meet the service challenges presented, operators need to follow a strategic and focused approach to the problem. Only by making careful, well-planned choices in next generation technology will today’s operators survive in an increasingly competitive market. Real data rate performance gains over the average system cell are thus of great interest, in order to provide sustainable decision on the migration.

Very complete simulators have been already developed, [2], [3] and [4], for both link level and network level perspectives. Also, trial tests on LTE performance [5], [6] and [7] have been carried out. While simulation provides for a very accurate analysis, in practice either due to varying implementation options, environment characteristics or due to practical matters on users’ behaviours, results differ drastically. Similarly, manufacturers’ measurements results validity is limited by the same reasons, while enhancing system performance is also of the manufacturer’s best interest. A different approach is suggested, by combining both simulation and measurements in a live LTE network. This is expected to be of great practical value for radio planners and service developers, interested in an extensive performance comparison, as well as for strategic

Figure 1. Traffic growth versus revenue in mobile communications [1].
decision-makers, evaluating the migration to the next generation technology.

This work was made in collaboration with the Portuguese telecom operator Optimus, with whom several technical details and work assumptions have been discussed.

In this paper, Section II describes the models for the theoretical calculations. Default scenarios are then presented and analysed in Section III for both Downlink (DL) and Uplink (UL). Finally, in Section IV the main work conclusions are drawn.

II. THEORETICAL MODELS

To assess HSPA+ and LTE capacity and coverage, in DL and UL, a model was developed based on one cell. For a capacity analysis, and given a certain distance to the Base Station (BS), maximum physical layer throughput is computed, within a set of parameters. System coverage, on the other hand, is evaluated for a fixed service data rate per user and maximum cell radius obtained.

Initially, considering only one cell user, total resource availability and perfect propagation conditions are assumed. Using a link budget analysis, users’ Signal-to-Interference-plus-Noise-Ratio (SINR) is computed and then mapped on user throughput based on manufacturer’s documentation gathered within the 3rd Generation Partnership Project (3GPP). For SINR computation, system parameters are considered, namely antenna configuration, modulation scheme, environment, channel type, signalling overhead, among others. Frequency is also considered, and bandwidth available in LTE.

The link budget analysis is similar for both HSPA+ and LTE, given the specific set of parameters for each system. In LTE, however, there is no processing gain. SINR calculation, for both systems, is given by [8]:

\[
p_{\text{SINR}}[\text{dB}] = P_{\text{Rx}}[\text{dBm}] - N_{\text{dBm}}[\text{dBm}] + G_{\text{r}}[\text{dB}],
\]

where:
- \( P_{\text{Rx}} \): SINR;
- \( P_{\text{Rx}} \): received power at receiver input;
- \( N \): total noise power;
- \( G_{\text{r}} \): processing gain;
- \( EIRP \): equivalent isotropic radiated power;
- \( L_{\text{p}} \): pathloss;
- \( G_{\text{a}} \): receiving antenna gain;
- \( L_{\text{ud}} \): user/cable losses.

Also, for total noise power in both systems, one has [8]:

\[
N_{\text{dBm}}[\text{dBm}] = N_{\text{BF}}[\text{dB}] + L_{\text{dBm}}[\text{dB}],
\]

where:
- \( N_{\text{BF}} \): average noise power at the receiver, given by:

\[
N_{\text{BF}}[\text{dBm}] = 174 + 10 \log(B) + F[\text{dB}],
\]

where:
- \( B \): bandwidth of the total RB’s allocated, while in UMTS it equals the chip rate;
- \( F \): noise figure of the receiver;
- \( I \): total interference power.

By considering other users in the cell, BS power split, in DL, and intra and inter-cell interferences, in UL and DL, SINR is obtained for UMTS. Similarly, considering Resource Blocks (RBs) split and inter-cell interference, LTE SINR is computed for both directions.

At each instant, users are spread over the cell at the same distance from the serving BS. Thus, for UMTS, BS power is split equally among active users, and the distribution of the orthogonality factor with distance presented in [9] is assumed. For LTE, available RBs are also equally divided among users.

UMTS intra-cell interference is computed considering each user’s distance to BS using expressions in [9]. For inter-cell interference, it is computed in the same way for both systems, [9], with the lack of the orthogonality factor for LTE and considering interference and noise in the effective bandwidth used. Moreover, Inter-Cell Interference Coordination (ICIC) schemes, either soft frequency reuse or partial frequency reuse, are available in LTE. For any of these, inter-cell interference is reduced resulting in improved SINR levels in UL and also in DL, differently for both cell centre and cell edge users, as in [10] and [11]. Hence a SINR ICIC gain is defined relative to the case of Universal Frequency Reuse (UFR) is used:

\[
\rho_{\text{ICIC}}[\text{dB}][\text{dB}] = \rho_{\text{ICIC}}[\text{dB}][\text{dB}][\text{dB}] + G_{\text{ICIC}}[\text{dB}],
\]

where:
- \( G_{\text{ICIC}} \): ICIC gain.

For a coverage analysis between systems, the COST231-Walfisch-Ikegami pathloss model is considered, as in [8], defining pathloss as:

\[
L_{\text{P}}[\text{dB}] = EIRP[\text{dBm}] - L_{\text{p}}[\text{dB}] + G_{\text{r}}[\text{dB}]
\]

\[
= L_{\text{P}}[\text{dB}] + L_{\text{FD}}[\text{dB}] + L_{\text{DS}}[\text{dB}],
\]

where:
- \( L_{\text{P}} \): free space loss;
- \( L_{\text{FD}} \): rooftop-to-street diffraction and scatter loss;
- \( L_{\text{DS}} \): approximation for the multi-screen diffraction loss.

Conversely, for a fixed required throughput value, maximum cell radius can be obtained. Requested physical throughput is mapped onto SINR which provides for computing receiver sensitivity. Then, taking the expressions for \( L_{\text{P}} \) and \( L_{\text{FD}} \), [8], cell radius can be expressed as:

\[
r_{\text{cell}}[\text{m}] = 10^{\frac{L_{\text{P}}[\text{dB}] - L_{\text{FD}}[\text{dB}] - L_{\text{DS}}[\text{dB}]}{10}},
\]

where:
- \( k_{\text{JD}} \): dependence of the multi-screen diffraction loss versus distance;
- \( L_{\text{COST231}} \): propagation losses over the propagation model being:

\[
L_{\text{COST231}}[\text{dB}] = L_{\text{P}}[\text{dB}] + L_{\text{FD}}[\text{dB}] + L_{\text{DS}}[\text{dB}],
\]

where:
- \( L_{\text{P}}[\text{dB}] = 20 \log_{10}(d_{\text{JD}}) \);
For LoS conditions, a similar expression can be also derived, resulting:

\[ L_{\text{LoS}} = 10 \log_{10} \left( \frac{r_{\text{km}}^{10} \cdot d_{\text{km}}^{10}}{r_{\text{km}}^{10}} \right) - 10 \log_{10} \left( \frac{r_{\text{km}}^{10}}{r_{\text{km}}^{10}} \right), \]  

(8)

where:

- \( L_{\text{LoS}} \): propagation losses over the propagation model being:

\[ L_{\text{LoS}} = L_p + 20 \log_{10} (d_{\text{km}}) + 20 \log_{10}(f_{\text{MHz}}), \]  

(9)

where:

- \( f \): frequency in use.

## III. RESULTS ANALYSIS

### A. Scenarios

For the performed analysis, different environment, channel and load conditions were considered. Table I shows environments considered. While for the Axial environment transmission is made in Line-of-Sight (LoS) between user and serving BS, for the urban environments, i.e. Urban and Dense Urban (DU), higher Inter-Site Distance (ISD) exists, i.e., lower Inter-Site Distance (ISD). Considered urban environments characteristics are further characterised as in Table II.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Axial</td>
</tr>
<tr>
<td>LoS</td>
<td>Yes</td>
</tr>
<tr>
<td>Average ISD [km]</td>
<td>0.816</td>
</tr>
<tr>
<td>Building Concentration</td>
<td>None</td>
</tr>
</tbody>
</table>

TABLE II. URBAN ENVIRONMENTS’ CHARACTERIZATION.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Urban</td>
</tr>
<tr>
<td>BS Height [m]</td>
<td>30</td>
</tr>
<tr>
<td>MT Height [m]</td>
<td>1.5</td>
</tr>
<tr>
<td>Buildings Height [m]</td>
<td>23</td>
</tr>
<tr>
<td>Street Width [m]</td>
<td>35</td>
</tr>
<tr>
<td>Inter Buildings Distance [m]</td>
<td>75</td>
</tr>
<tr>
<td>Incidence Angle [º]</td>
<td>90</td>
</tr>
</tbody>
</table>

Furthermore, two different channel scenarios are defined: the pedestrian and vehicular channels. While the former stands for a static user (or almost, 3km/h in ITU Pedestrian A channel) at street level, the vehicular stands for users moving at high speed, normally 50km/h are considered.

Default parameters for link budget estimation are listed in TABLE III and TABLE IV, based on [12] and [13]. Same Maximum BS and Mobile Terminal (MT) power, as well as BS and MT gains, are assumed for both systems for a fair comparison between the two systems. Whereas for UMTS the usual 5 MHz bandwidth is considered, for LTE the maximum bandwidth of 20 MHz is used. Nevertheless, maximum LTE throughputs for 5 MHz are easily obtained by dividing throughput values presented in the same proportion.

A SINR threshold level is defined for both systems, above which Multiple-Input Multiple Output (MIMO) transmission takes place. For LTE, the value is taken from measurements described in the next section. Also for LTE, values for ICIC SINR gains are considered differently for cell centre and edge users, [10] and [11], independently of the specific scheme chosen.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>DL</th>
<th>UL</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS Transmission Power [dBm]</td>
<td>46</td>
<td>-</td>
</tr>
<tr>
<td>MT Transmission Power [dBm]</td>
<td>-</td>
<td>24</td>
</tr>
<tr>
<td>Frequency Band [MHz]</td>
<td>2110</td>
<td>1920</td>
</tr>
<tr>
<td>Bandwidth [MHz]</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Modulation</td>
<td>QPSK, 16QAM, 64QAM</td>
<td>QPSK, 16QAM</td>
</tr>
<tr>
<td>Antenna Configuration</td>
<td>SISO, MISO, MIMO</td>
<td>SISO</td>
</tr>
<tr>
<td>MT Antenna Gain [dB]</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>BS Antenna Gain [dB]</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>User Losses [dB]</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Cable Losses [dB]</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Noise Figure [dB]</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>Signalling and Control Power [%]</td>
<td>40</td>
<td>15</td>
</tr>
<tr>
<td>MIMO SINR Threshold[dB]</td>
<td>17.3</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>DL</th>
<th>UL</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS Transmission Power [dBm]</td>
<td>46</td>
<td>-</td>
</tr>
<tr>
<td>MT Transmission Power [dBm]</td>
<td>-</td>
<td>24</td>
</tr>
<tr>
<td>Frequency Band [MHz]</td>
<td>2630</td>
<td>2510</td>
</tr>
<tr>
<td>Bandwidth [MHz]</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Modulation</td>
<td>QPSK, 16QAM, 64QAM</td>
<td>QPSK, 16QAM</td>
</tr>
<tr>
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<td>SISO, MISO, MIMO</td>
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</tr>
<tr>
<td>MT Antenna Gain [dB]</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>BS Antenna Gain [dB]</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>User Losses [dB]</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Cable Losses [dB]</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Noise Figure [dB]</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>ICIC Gain [dB]</td>
<td>Cell Centre</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Cell Edge</td>
<td>10</td>
</tr>
<tr>
<td>Signalling and Control Power [%]</td>
<td>28.5</td>
<td>10</td>
</tr>
</tbody>
</table>

Regarding interference, users in the same cell are all assumed to transmit at the same power in UL. However, although users
in the cell under study are considered to be at maximum load, i.e., transmitting with maximum power in both UL and DL, neighboring cells are considered to serve the same amount of users but at 50% of maximum transmitted power. Therefore, in DL, neighboring BS’s maximum transmitted power is 42.97 dBm, TABLE V, and 21 dBm in UL.

Additionally, for the capacity analysis users are considered to be distributed at a given distance from serving BS, characterized by a Gaussian distribution with the same mean and standard deviation as considered in the measurements results, for each environment. Conversely, regarding coverage, three service types are considered for both UL and DL: a 1 Mbps Web service, a 5 Mbps Video Streaming service and a 10 Mbps File Transfer Protocol (FTP) service.

**TABLE V. NEIGHBOURING BS’S TRANSMITTED POWER.**

<table>
<thead>
<tr>
<th>Cell load [%]</th>
<th>Neighbouring BS power [dBm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>41.2</td>
</tr>
<tr>
<td>50</td>
<td>42.97</td>
</tr>
<tr>
<td>75</td>
<td>44.73</td>
</tr>
<tr>
<td>100</td>
<td>46</td>
</tr>
</tbody>
</table>

**B. Measurements Results**

Measurements were made in cooperation with Optimus over the considered scenarios. Regarding environments, higher average SINR and throughput exist in the Axial environment, regarding the Urban and DU environments, TABLE VI. Figure 2-a) shows average usage rates of the Space-Frequency Block Coding (SFBC) mode, a receive-diversity scheme, and the Open-Loop Spatial Multiplexing (OL SM) mode, a 2×2 MIMO scheme, as a function of SINR. A similar analysis is shown regarding the Modulation and Coding Scheme (MCS) index, Figure 2-b). For MIMO, SINR levels above 17 dB are required for average transmission rates above 10% in Urban environment. For Axial and DU environments thresholds of 16 dB and 16.5 dB exist, considerably higher than the 10 dB threshold considered in [14] for a spatially uncorrelated channel.

**TABLE VI. ENVIRONMENT PERFORMANCE.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Axial</td>
</tr>
<tr>
<td>$\mu_{\text{mean}}$ [dB]</td>
<td>18.11</td>
</tr>
<tr>
<td>$\sigma_{\text{error}}$ [dB]</td>
<td>2.44</td>
</tr>
<tr>
<td>$\mu_{\text{throughput}}$ [Mbps]</td>
<td>82.04</td>
</tr>
<tr>
<td>$\sigma_{\text{throughput}}$ [Mbps]</td>
<td>39.67</td>
</tr>
</tbody>
</table>

As shown in [9], 82% of measurements in the Axial environment are above 16 dB, mainly boosted by high ISDs and low pathloss, compared to 60% and 41% in Urban and DU environments. Thus higher MIMO average transmission rates were measured for the former, 46% compared to 7% and 9% in Urban and DU environments, Figure 3-a), which mainly boosts average data rates measured. Additionally higher average use rates for 64QAM, also allow for improved data rate performance, Figure 3-b).

Furthermore, SINR gains of 3.7 dB, 0.05 dB and 0.87 dB were measured in [9] from mobility to the static scenarios, in Axial, Urban and DU scenarios, respectively. Thus, apart for the Axial environment, no significant differences are seen due to mobility.

Regarding cell centre to cell edge performance, great differences are measured across the cell as shown in Figure 4 and TABLE VII. A decrease of 5.65 dB, 4.74 dB and 4.97 dB is measured in average SINR from centre to edge, respectively for Axial, Urban and DU environments, with associated reduction of 54%, 55% and 41% in average throughput. As no ICIC schemes were in use, inter-cell interference is mainly responsible for this performance reduction over the cell. Furthermore, a threshold of around 15 dB to 16 dB can be defined in Figure 4 for separating cell centre from cell edge users.

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and 37% in throughput are shown from the 0% load scenario to the 50%, 75% and 100% ones, respectively. The effect of growing inter-cell interference provides for the performance decrease.

TABLE VII. CELL CENTRE VERSUS CELL EDGE PERFORMANCE.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Axial</th>
<th>Urban</th>
<th>DU</th>
</tr>
</thead>
<tbody>
<tr>
<td>μ[SINR] [dB]</td>
<td>11.82</td>
<td>17.47</td>
<td>13.46</td>
</tr>
<tr>
<td>σ[T] [Mbps]</td>
<td>31.04</td>
<td>68.10</td>
<td>28.83</td>
</tr>
</tbody>
</table>

TABLE VIII. NEIGHBOURING CELL LOAD PERFORMANCE IN URBAN ENVIRONMENT.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Load [%]</th>
<th>0</th>
<th>50</th>
<th>75</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>μ[SINR] [dB]</td>
<td>14.75</td>
<td>8.71</td>
<td>6.46</td>
<td>5.88</td>
<td></td>
</tr>
<tr>
<td>σ[SINR] [dB]</td>
<td>4.53</td>
<td>7.21</td>
<td>6.65</td>
<td>6.78</td>
<td></td>
</tr>
<tr>
<td>μ[Throughput] [Mbps]</td>
<td>43.72</td>
<td>39.44</td>
<td>29.12</td>
<td>27.39</td>
<td></td>
</tr>
<tr>
<td>σ[Throughput] [Mbps]</td>
<td>20.08</td>
<td>30.24</td>
<td>19.01</td>
<td>19.14</td>
<td></td>
</tr>
</tbody>
</table>

Particularly regarding cell centre to edge performance, a reduction of 14 dB, 10 dB and 8 dB in average SINR is seen for Axial, Urban and DU environments, respectively, with an associated throughput decrease of 80%, 66% and 65%, Figure 5 and Figure 6.

C. Simulation Results

In a multi-user analysis, inter-cell interference power limits LTE’s SINR, remaining constant for increasing number of users in the cell, Figure 7. However, for UMTS, also intra-cell interference exists and, together with BS power split, is responsible by the steep SINR decrease as a function of the number of users. For the single-user case, UMTS provides still for the highest SINR, although not associated to the highest throughputs, compared to LTE, Figure 8. Average throughputs of 37.79 Mbps, 64.22 Mbps, 94.13 Mbps and 150.31 Mbps are obtained using using UMTS, LTE UFR, LTE ICIC and LTE ICIC 4×4 in single-user Urban scenario.

Significant increases in throughput, e.g. by factors of 1.39 and 3.21 for single-user, are obtained through the use of ICIC and ICIC together with advanced MIMO, respectively. High throughput ratios exist from HSPA+ to LTE, e.g. 4.31, 6.04 and 9.78 for LTE UFR, LTE ICIC and LTE ICIC 4×4 in five-users scenario, Figure 9. Furthermore, average data rate ratio grows logarithmically with the number of users, [9].

![Figure 5](image1.png)

![Figure 6](image2.png)

![Figure 7](image3.png)

![Figure 8](image4.png)

![Figure 9](image5.png)
As further shown in [9], similar results are also obtained for remaining Axial and DU environments, with SINR gains no higher than 1 dB and losses of up to 3 dB in LTE UFR, respectively, regarding the Urban environment. In UMTS environments, differences lower than 0.4 dB exist for both Axial-Urban and Urban-DU transitions, in multi-user scenario. Similarly, differences of 0.08, 0.31 and 0.17 and of -0.6, -0.56 and -1.51 exist in throughput ratios for LTE UFR, LTE ICIC and LTE ICIC 4 × 4 in five-users scenario, for Axial and DU environments.

Conversely, UMTS provides for greater cell ranges than LTE UFR in the single-user scenario, Figure 10, although lower ranges are obtained in multi-user scenario, over all environments [9]. Again, BS power split and intra-cell interference rise provide for a steep decrease in average cell range for UMTS, while for LTE inter-cell interference and the number of available RBs per user restrict results.

For a 5 Mbps service data rate, cell ranges of 0.13 km, 0.26 km and 0.48 km are obtained for UMTS, LTE UFR and ICIC variants in five users scenario. For the same scenario, cell range gains of 24% and losses of 36% exist for LTE UFR, from Urban to Axial and DU environments, respectively, [9]. Moreover, cell range gains of 146% and losses of 23% are measured from 5 Mbps to 1 Mbps and 10 Mbps service data rates, respectively, in Urban environment for LTE UFR.

![Average distance vs Number of users](image1)

**Figure 10.** Coverage results for the Urban pedestrian scenario, for required 5Mbps DL throughput service.

Regarding cell performance, due to fast power control in UMTS, the distribution of BS power, in DL, depends on the UE’s distance to the serving BS. In an optimal power control scheme, no difference exists between cell edge users and cell centre users. Further, as intra- and inter-cell interferences increase near cell centre and cell edge, respectively, a smoother transition exists, [9]. Regarding LTE UFR, Figure 11, significant SINR drops occur from cell centre to edge, with associated decreases of 57.4%, 56.5% and 54.6% in throughput for Axial, Urban and DU environments, respectively. Further, ICIC schemes allow for SINR gains of up to 6dB in cell edge and 10 dB in cell centre, improving throughput edge-to-centre gap to 18.1%, 18.4% and 22.8%, respectively, [9].

For UL, similar analyses are presented for capacity and coverage. While in the multi-user scenario inter-cell interference power still limits LTE’s SINR, now interference increases for increasing number of users in the cell under study as in the neighbouring cell, reducing SINR, Figure 12. For UMTS, mainly intra-cell interference limits performance and, most strikingly, provides for the SINR drop seen from single-to multi-user scenarios. For the single-user case, UMTS and LTE ICIC provide for similar SINR levels, although differences are seen in throughput, Figure 13.

![Average distance vs Number of users](image2)

**Figure 11.** Cell centre to cell edge LTE UFR performance for pedestrian channel in DL.

Average data rates of 11 Mbps, 57 Mbps and 70 Mbps are obtained using UMTS, LTE UFR and LTE ICIC, respectively, for single-user. Despite the high average throughputs for LTE, the use of ICIC schemes provides for smaller gains than for DL, only 23% in single-user scenario, mainly because high SINR levels are already obtained with LTE UFR for this scenario.

![Average distance vs Number of users](image3)

**Figure 12.** UL SINR for Urban pedestrian scenario, for varying number of users.

![Average distance vs Number of users](image4)

**Figure 13.** UL throughput for Urban pedestrian scenario, for varying number of users.

Also for UL, high throughput ratios are obtained from HSPA+ to LTE, namely 7.29 and 10.46 for LTE UFR and LTE ICIC in
five users Urban scenario, Figure 14. Differently from DL, in UL a rising tendency is seen until the three users in the cell scenario, and stabilizes for higher number of users mainly due to the marginal throughput levels in UMTS and a slower decrease in LTE, due to RBs split.

Similar results are also obtained for Axial and DU environments, with measured SINR gains no higher than 5 dB and losses lower than 8 dB in LTE UFR, regarding the Urban, [9]. For UMTS differences lower than 0.7 dB in both Axial-Urban and Urban-DU transitions, except for the single-user scenario. Accordingly, differences of 2.08 and 1.24 and of -2.61 and -2.26 are thus seen LTE UFR and LTE ICIC throughput ratios in five-users scenario, for Axial and DU environments.

![Figure 14. UL throughput ratio for Urban pedestrian scenario, for varying number of users.](image)

In a coverage analysis, LTE provides always for the highest cell ranges, Figure 15. In this scenario, UMTS intra-cell interference rise provides for average cell range decrease while LTE is only limited by inter-cell interference and by the number of available RBs. For 5 Mbps with five users, 0.52 km and 0.96 km ranges are measured while no coverage is obtained using UMTS.

![Figure 15. Coverage results for the Urban pedestrian scenario, for required 5Mbps UL throughput service.](image)

Nevertheless, higher UL ranges are obtained than for DL, and thus for a symmetric service, it is seen that the coverage limit is supported by the DL direction. Gains of 43% and -52% exist though in average cell range from Urban to Axial and DU environments in the latter scenario for LTE UFR, [9]. Regarding 1 Mbps, a gain of 44% is obtained for LTE UFR in the five users Urban scenario.

For cell centre versus cell edge performance in UMTS, power control together with intra/inter-cell interferences rise near cell centre/edge provide once more for a smoother performance transition between the two regions, [9]. In LTE, however, a centre-to-edge gap of 14 dB in SINR and 53% in throughput is measured for five users in LTE UFR for the Urban scenario, Figure 16 and Figure 17. The use of ICIC schemes can even improve SINR levels in both centre and edge, by 6 dB and 10 dB respectively, reducing the gap to 11 dB. In this case, cell edge performance is brought to throughput levels similar to cell centre ones, Figure 17, with only a 25% gap.

![Figure 16. Cell centre to cell edge LTE SINR performance for pedestrian channel in UL.](image)

![Figure 17. Cell centre to cell edge LTE throughput performance for pedestrian channel in UL.](image)

IV. CONCLUSIONS

This paper addresses a performance comparison between HSPA+ and LTE, focusing on coverage and capacity aspects at the cellular level. Measurements in a live LTE network are taken for DL in a single-user scenario and a simple theoretical approach is considered for an evaluation of the multi-user scenario.

Measurements are analysed for varying environment, channel, modulation and antenna configuration schemes, user’s position and cell load scenarios. Average throughput values of 82 Mbps, 50 Mbps and 42 Mbps are obtained for static Axial, Urban and DU environments with LTE UFR. For the Axial environment, throughputs are boosted mainly due to MIMO transmission. SINR MIMO thresholds, above which more than 10% of MIMO usage occurs, are measured. Thresholds of 16 dB, 17 dB and 16.5 dB exist for Axial, Urban and DU environments. Regarding modulation, 64QAM is the preferred
modulation scheme, with 74% average use over all environments, against 22% for 16QAM and 4% for QPSK.

Users’ position in the cell is determined to directly impact obtained data rate, and a throughput reduction of 55% is obtained from cell centre to cell edge due to SINR differences of 4 dB in Urban environment. Furthermore, the centre cell to cell edge SINR threshold of 15 dB to 16 dB is defined for all environments. Also, data rate reductions of 10%, 33% and 37% exist from 0% to 50%, 75% and 100% load scenarios, respectively, in the Urban environment.

Comparing then HSPA+ with LTE, for the single cell model, DL average data rates of 38 Mbps, 64 Mbps, 94 Mbps and 150Mbps are obtained using UMTS, LTE UFR, LTE ICIC and LTE ICIC 4x4 in single-user Urban scenario. For five users scenario UMTS to LTE throughput ratios of 4.31, 6.04 and 9.78 for LTE UFR, LTE ICIC and LTE ICIC 4x4 are obtained, whereas these were proved to grow logarithmically with the number of users.

In coverage, UMTS provides for greater cell ranges than LTE UFR in the single-user scenario, although an inversion occurs in multi-user scenario over all environments. For a 5 Mbps service data rate, cell ranges of 0.13 km, 0.26 km and 0.48 km are obtained for UMTS, LTE UFR and ICIC variants in five users Urban scenario. Though a smooth cell centre to edge transition occurs in UMTS, a throughput decrease of 56.5% and 18.4% exists from centre to edge using LTE UFR and LTE ICIC in Urban environment.

For the UL, average data rates of 11 Mbps, 57 Mbps and 70 Mbps are obtained in UMTS, LTE UFR and LTE ICIC for one user in the Urban environment. For five users, throughput ratios of 7.29 and 10.46 are obtained from UMTS to LTE UFR and LTE ICIC, respectively, whereas the same difference is maintained for higher number of users.

Regarding coverage, LTE provides for the highest cell ranges over all scenarios. For a 5 Mbps service data rate, ranges of 0.52 km and 0.96 km are obtained for LTE UFR and LTE ICIC in Urban environment, while for UMTS users cannot be served. Higher ranges are obtained for UL than for the same service throughput in DL, considered the constraining link for this matter. Even similar average decreases are seen in throughput from cell centre to edge, 53% for UL, in a five users with LTE UFR. Through ICIC schemes the centre-to-edge throughput gap can be reduced to 25%.

All in all, through the capacity and coverage analyses taken, it is seen that higher performance is obtained by the use of LTE for the studied scenarios. However, performance results vary for differently scenarios, namely environment, e.g. ISD, user’s distribution in the cell, BS building concentration, etc. and cell load scenarios, among others. Thus comparative studies should be carried across scenarios of interest, and a critical analysis should always be taken when comparing results obtained within different assumptions.

REFERENCES


