Abstract — Wireless radio technologies are continuously in progress, catching up to the rise of new challenging applications. Recent releases of UMTS/HSPA+ and LTE, two dissimilar systems, are evaluated in terms of performance in a dual scenario regarding the number of users. A single user model is developed aiming at the cell radius calculation, concerning a certain requested throughput and employing all available system resources. Additionally, the multiple users’ model presents a further realistic approach with shared resources in a random fading channel. Given the differences between the two technologies, the impact of some system metrics was taken into account throughout the two models. In the single user case, one show that more robust modulations lead to a higher radius, while in indoors, coverage constraints were detected, especially in UL with cell radii below 100 m. When the number of users increases, as far as performance is concerned, LTE unveils higher average network throughput of 13.5 Mbps and an average ratio of served users of 72% compared to 9.8 Mbps and 66% in UMTS/HSPA+, however, the latter covers 36% more users. In addition, LTE presented superior results over almost all analysed situations.

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

I. INTRODUCTION

Mobile communications systems revolutionised the way people communicate, joining together communications and mobility. The basic need for communication between people is the dominant driver for the telecoms business, [1].

The growing demand for mobile Internet and wireless multimedia applications has motivated the development of broadband wireless access in recent years. With an even-closer approximation between wireline and wireless technologies in terms of performance, the old traditional differences between them are getting increasingly similar. In a near future, the telecommunications area can expect a trade-off between wireless and wireline systems, standing for enhancements of wireless radio spectral efficiency achievements and consequent offered performance for such mobility, especially on low density areas or even on developing countries.

The perspectives are optimistic towards an exponential increase of data traffic within wireless networks, supported by the performance of certain applications, in the past classified as “killer-applications”, whereas now starting to be feasible, like video-on-demand, HD video conference and HD TV, robust online gaming, other person-to-person services or even 3DTV. Portuguese communications regulatory entity, Anacom, shows that the actual number of mobile broadband subscriptions surpasses the number of wireline subscribers. Moreover, Ahonen in [2] affirms that Portugal has past 130% phone penetration level and nowadays exist around 4.3 billion mobile subscriptions worldwide.

Third Generation (3G) systems, e.g., the Universal Mobile Telecommunications System (UMTS), were designed for multimedia communications improved by the higher data rates and new flexible communication capabilities, [3] comparing with 2G systems. Its specifications have been created by 3rd Generation Partnership Project (3GPP), also responsible for important evolution steps, e.g., High Speed Packet Access (HSPA) known as a 3.5G technology, widely adopted nowadays, and 3GPP’s Release 7 and 8, namely HSPA Evolution (HSPA+). Key features introduced in each 3GPP release and peak that rates are shown in Fig.1.

Figure 1. 3GPP technologies progression and associated enhancements.

The aim of Release 7 is to improve the performance of Wideband Code Division Multiple Access (WCDMA) through higher peak data rates, lower latency, greater capacity and increased MT battery time. Multiple Input Multiple Output (MIMO) and Higher Order Modulation (HOM) extend the previous releases capacity. However, initial deployments of LTE will be best suited for urban hot spots, whereas HSPA+ will cover the existing vast HSPA footprint, [4].

In order to accomplish present and future demands of mobile broadband, the 3GPP specified the Long Term Evolution (LTE), a complete new wireless technology, offering a number of enhancements, providing major improvements to end-user performance and network efficiency. The constant performance increase requirements are met by a flexible and spectrally efficient radio link.
protocol with low overhead, which meets the challenging targets, [5].

The new system’s access technique is based on Single Carrier – Frequency Division Multiple Access (SC-FDMA) for UL and OFDMA in DL with the use of cyclic prefix (CP). The physical layer parameters were designed in such a way that backward-compatibility is ensured, employing simple multimode GSM/WCDMA/LTE devices, making possible the signalling to/from GSM/UMTS for handovers to enable seamless mobility.

For FDD mode it is specified the frame structure type 1 with 12 consecutive sub-carriers and 7 consecutive OFDMA symbols (66.7 μs each) over a slot duration (0.5 ms), resulting in a Resource Block (RB). An RB has 84 resource elements (12 sub-carriers x 7 symbols) corresponding to one slot in the time domain and 180 kHz (12 sub-carriers x 15 kHz spacing) in the frequency domain. The size of a RB is the same for all bandwidths; therefore, the number of available physical RBs depends on the channel bandwidth. The number of available RBs can range from 6, when transmission bandwidth is 1.4 MHz, to 100, when transmission bandwidth is 20 MHz. A CP is appended to each symbol as a guard interval higher than the channel delay spread, in order to mitigate Inter Symbolic Interference (ISI). OFDMA brings advantage compared to SC modulations, revealing an increased robustness against frequency selective fading and narrowband interference, since a single fade in SC systems can interfere with the entire link, in multi-carrier configurations only a few sub-carriers are affected.

This work was made in collaboration with the Portuguese mobile telecommunications operator Vodafone, which several technical details and work assumptions were discussed.

In Section II the models for the theoretical calculations are described. A default scenario is presented and analysed in Section III as well some parameters variation for UL. Finally, in Section IV the main work conclusions are drawn.

II. THEORETICAL MODELS

To assess HSPA+ and LTE in terms of coverage and capacity, two models were developed: the Single User and the Multiple Users one. The first one is intended to assess the maximum cell radius in a single user scenario, Fig.2, which can be used in a network planning phase to estimate cell radius, whereas the second is intended to evaluate HSPA+ and LTE performance with a further realistic approach, analysing a different scenario, with several users performing multiple services, being randomly spread over the Base Station (BS) coverage area.

![Figure 2. Cell edge definition at the Single User’s Model.](image)

### A. Single User

HSPA+ single user model was developed, allowing the calculation of maximum cell radius according to several system parameters, as the desired throughput, antenna configuration, modulation scheme, environment, overhead charge, among others. On the other hand, for LTE the same approach was followed, but in addition some exclusive parameters such as channel bandwidth or different possible deploying frequency bands as 900 and 2600 MHz were considered.

The cell radius calculation is similar both for HSPA+ and LTE, the differences being the calculation of the receiver’s sensitivity, i.e., minimum receive power for the user being served with the requested throughput. For HSPA+ the available throughput is calculated based on the Signal-to-Noise Ratio (SNR) and $E/N_0$ trials performed in [6]. On the other hand, LTE’s available throughput is calculated based on SNR measurements taken in [7] and [8].

It is important to note that, all system resources available are allocated to the user, not taken into account interference, and assuming perfect propagation conditions. The path loss is calculated using the link budget detailed in [9]. From the COST231-Walfisch-Ikegami propagation model, [10] one has:

$$L_{\text{path}} = L_{\text{path}} + L_{\text{path}} + L_{\text{path}} = EIRP_{\text{path}} - P_{\text{path}} + G_{\text{path}} - M_{\text{path}},$$

(1)

where:

- $L_d$: free space loss;
- $L_{tt}$: roof-top-to-street diffraction loss;
- $L_{tt}$: approximation for the multiscreen diffraction loss;
- $EIRP$: equivalent isotropic radiated power;
- $P_r$: available receiving power at the antenna port;
- $G_r$: receiving antenna gain;
- $M_{\text{total}}$: total margin, hence, slow and fast fading contributions plus penetration margin.

Then, from the COST231-Walfisch-Ikegami model, the cell radius can be calculated by:

$$R = 10^{-rac{L_{\text{path}}}{20k_d}},$$

(2)

where:

- $L_{\text{path}}$: total margin, hence, slow and fast fading contributions plus penetration margin;
- $k_d$: dependence of the multiscreen diffraction loss versus distance;
- $d$: distance between the user and the BS;
- $R$: maximum cell radius.

### B. Multiple Users

The multiple users’ model was developed in C++, adapted and optimised from the one in [11] and [12] into a MapInfo running simulator. New HSPA+ and LTE modules were added, both for DL and UL, in order to compare with same conditions both systems. In addition, new routines were adapted to fit models from [6], [7] and [8] with the extract purpose of maximum system performance conditions for new services types. Also, was implemented Adaptive Modulation (AM) algorithms given the available channel information for HSPA+ and LTE both for DL and UL.

The HSPA+ and LTE modules’ main purposes are the analysis of the network coverage and capacity, through a snapshot approach, calculating several network metrics such as SNR, Ec/No, and others.
as radius, average network throughput, total network traffic, along with others. These modules perform an analysis on a BS basis, being executed in all network BSs. Simulations were carried out and the city of Lisbon was set as scenario considering 194 co-located BSs and an average of 1600 users spread non-uniformly. Subsequently, the modules compute network averages regarding some of the parameters recorded per BS and, in addition, extrapolate some results for the ‘busy hour’ analysis, i.e., the most demanding period of the day when the probabilities of congestion are higher.

Reference services are used to define the BS coverage radius, being calculated for a reference throughput taken as the theoretical performance limit of HSPA both in DL and UL.

When the offered traffic exceeds the BS’s capacity, one of three reduction strategies with different Quality of Service (QoS) requirements is applied. The definition of the maximum DL throughput supported is related to the chosen system parameters. For HSPA+, MIMO 2x2 configuration and 64 Quadrature Amplitude Modulation (QAM) modulation scheme is used for DL respectively, while for LTE both previous parameters are set for a 10 MHz channel bandwidth operating at 2.6 GHz. MIMO improvements were predicted in lack of information cases with the use of Relative MIMO Gain (RMG) model, [13]. Even when 3GPP specifications do not consider MIMO for UL, model extrapolations were done, in order to face the available data performing a fair system comparison. For UL, 64 QAM is also not specified, so 16 QAM was considered, following similar DL assumptions.

One of the main differences between the single model and the multiple users’ model is the resources allocation, whereas in the latter, those are shared among all users. Furthermore, in multiple users’ model it was needed to take into account interference phenomena, parameter used to emulate the load in the cell. The interference margin calculation is described in detail in [14]. Due the interference margin consideration, the path loss decreases, leading to a lower cell radius or throughput, when one compares the single user with the cell. The interference margin calculation is obtained by a different approach from the one used in the single user model. While in the latter the objective is to calculate the maximum cell radius, in the former, the cell radius is defined as the distance of the user served farther away from the BS, (6). One should mention that the capacity limits the cell radius, since when the reduction strategies are applied, users farther away from the BS have a higher probability of being delayed, leading to a reduction of the BS cell radius.

For the network analysis, the most important parameters taken into account were the average network radius, \( \bar{r}_{\text{net}} \), the average satisfaction grade, \( \overline{S_{\text{net}}} \), the average throughput, \( \bar{R}_{\text{net}} \), and the average network throughput, \( \bar{R}_{\text{net}} \).

The cell radius, \( r_{\text{BS}} \), is given by:

\[
r_{\text{BS}} \text{ [km]} = \frac{\sum_{j=1}^{N_{\text{BS}}} d_{\text{max user}_j} \text{[km]}}{\beta} ,
\]

where:
- \( d_{\text{max user}_j} \) is the distance to the BS of the furthest user considering tri-sectorized BSs;
- \( r_{\text{BS}} \) is the BS radius.

The average network radius, \( \bar{r}_{\text{net}} \):

\[
\bar{r}_{\text{net}} = \frac{\sum_{j=1}^{N_{\text{BS}}} r_{\text{BS}}}{N_{\text{BS}}} ,
\]

where:
- \( r_{\text{BS}} \) is the BS radius;
- \( N_{\text{BS}} \) is the number of active BSs.

The average satisfaction grade, \( \overline{S_{\text{net}}} \):

\[
\overline{S_{\text{net}}} = \frac{\sum_{j=1}^{N_{\text{BS}}} S_{G,j}}{N_{\text{BS}}} ,
\]

where:
- \( S_{G,j} \) is the satisfaction grade of a BS, which results in the ratio between the total served throughput and the total requested throughput.

The average ratio of served users, \( \overline{S_U} \):

\[
\overline{S_U} = \frac{\sum_{j=1}^{N_{\text{BS}}} N_{\text{alt}_{\text{BS}j}}}{N_{\text{alt}_{\text{TOT}}}} ,
\]

where:
- \( N_{\text{alt}_{\text{BS}j}} \) is the number of users served in a BS;
- \( N_{\text{alt}_{\text{TOT}}} \) is the total number of covered users.

The average network throughput, \( \bar{R}_{\text{net}} \), is given by:

\[
\bar{R}_{\text{net}} = \frac{\sum_{j=1}^{N_{\text{BS}}} R_{\text{alt}_{\text{BS}[\text{Mbps}]}}}{N_{\text{BS}}} ,
\]
where:

- \( R_{BS} \): instantaneous served throughput in a BS.

It is important to emphasise that LTE resources are allocated by means of RBs, the user’s throughput is dependent on the respective RB allocation and the RB capacity according with system configuration.

The network dimensioning for the busy hour of the day is estimate by two metrics, the number of users, served in an hour, \( N_{\text{users}} \), and the total network traffic, \( T_{\text{net}} \), defined as:

\[
N_{\text{users}} = \sum_{j=1}^{N_{B}} N_{\text{shBS}} \tag{11}
\]

\[
T_{\text{net}[GB/h]} = \sum_{j=1}^{N_{B}} T_{\text{sh}[GB/h]} \tag{12}
\]

where:

- \( N_{\text{shBS}} \): number of users per hour in a BS.

### III. RESULTS ANALYSIS

#### A. Scenarios

Two dissimilar scenarios are considered for each developed model. All existent signal multipath are considered completely uncorrelated with the objective of apply the MIMO gains. The multiple users’ scenario contemplates the existence of several users uniformly distributed along the BSs coverage area, performing different services with different associated throughputs.

The environments considered for both models are pedestrian, vehicular, and indoor. In single user scenario, these environments are distinguished by the different fixed values of slow and fast fading margins as well as the penetration attenuation.

For the multiple users’ scenario, the indoor environment represents the largest users’ ratio, the most suitable location for users performing the type of services shown in Fig.3, highly associated to laptops. Five services with different QoS classes were considered with the default profile penetration percentages presented in Fig.3. Also, in this scenario, fading margins are statistical distributed.

![Figure 3. Penetration percentages of the default profile.](image)

The QoS priority levels for the considered services are presented in Table I. The first services to be reduced are the ones with higher QoS value. The possible throughput range for the services considered in UL and DL is also presented in Table I. For reference throughputs, it was set 14.4 Mbps in DL and 5.7 Mbps in UL for both systems, hence, the HSPA performance limits.

### Table I. Throughputs for HSPA+ and LTE.

<table>
<thead>
<tr>
<th>Service</th>
<th>Throughput [Mbps]</th>
<th>QoS Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Constant</td>
<td>Variable</td>
</tr>
<tr>
<td>Web</td>
<td>[1.024, ( R_{\text{max}} )]</td>
<td>1</td>
</tr>
<tr>
<td>Streaming</td>
<td>[0.032, 10]</td>
<td>2</td>
</tr>
<tr>
<td>E-mail</td>
<td>[0.384, ( R_{\text{max}} )]</td>
<td>3</td>
</tr>
<tr>
<td>MMS</td>
<td>[0.128, 0.512]</td>
<td>4</td>
</tr>
<tr>
<td>FTP</td>
<td>[0.512, ( R_{\text{max}} )]</td>
<td>5</td>
</tr>
</tbody>
</table>

The higher throughputs reflect the users’ trend of requesting more demanding applications in terms of network capacity. Given that, it is important to underline that the services throughput is limited by the system configuration used, \( R_b \). Note also that, Streaming has a continuous throughput request that does not vary through the session time.

Concerning capacity features, it is important to focus that both systems have different Radio Resource Management (RRM) algorithms regarding the scheduling of the offered services. While LTE has available bandwidth for all types of services, in UMTS the services are divided into two carriers: voice and video-telephony are dedicated to the Release 99 carrier, while data services to the latest Release, hence, solely contributing to the comparison performed through this work, Fig.4.

![Figure 4. Distribution of services in UMTS and LTE.](image)

The HSPA+ and LTE traffic models characterisation are presented in [14] with no differentiation between the two systems. For Web and Streaming, the most asymmetric services, the increased UL traffic volume is explained by the rising of new web standards, Web 2.0, introducing greater user interaction on the production and content delivery through the network, whereas before, the most traffic corresponded to signalling and control processes. With respect to volume, the FTP and streaming are the services which sessions have a higher volume associated.

Antenna configurations, as Single Input Single Output (SISO), or Single Input Multiple Output (SIMO) with the spatial diversity application are considered. MIMO is considered as well.

The parameters used for the link budget estimation and the default values considered, are listed in Table II and Table III, based in [14] and [16]. The BS antenna gain is 18 dBi, with a 65º half power beam.

A body loss margin is established as 1 dB, and 1 dB for MT antenna gain, assuming that the equipment is not used next to the ear. LTE channel bandwidths analysed start from 5 MHz, the same used by UMTS, or higher. Also, an interference margin is set, in order to traduce a network tolerance in extreme cases of interference phenomenon. The BS transmission power is set to 46 dBm, for both systems, presuming only macro-cell coverage.
TABLE II. DEFAULT HSPA+ LINK BUDGET VALUES.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>DL</th>
<th>UL</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS DL 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>Modulations</td>
<td>QPSK, 16 QAM, 64 QAM</td>
<td></td>
</tr>
<tr>
<td>Bandwidth [MHz]</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Antenna Configurations</td>
<td>SISO, SIMO (UL), MIMO</td>
<td></td>
</tr>
<tr>
<td>MT Antenna Gain [dBi]</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>BS Antenna Gain [dBi]</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>Diversity Gain [dB]</td>
<td>---</td>
<td>2</td>
</tr>
<tr>
<td>Interference Margin [dB]</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Power reserved for signalling and</td>
<td></td>
<td></td>
</tr>
<tr>
<td>control issues (Release 99 + HSPA) [%]</td>
<td>40</td>
<td>15</td>
</tr>
</tbody>
</table>

TABLE III. DEFAULT LTE LINK BUDGET VALUES.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>DL</th>
<th>UL</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS DL 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>900, 1800, 2100, 2600</td>
<td></td>
</tr>
<tr>
<td>Modulations</td>
<td>QPSK, 16 QAM, 64 QAM</td>
<td></td>
</tr>
<tr>
<td>Bandwidth [MHz]</td>
<td>5, 10, 15, 20</td>
<td></td>
</tr>
<tr>
<td>Antenna Configurations</td>
<td>SISO, SIMO (UL), MIMO</td>
<td></td>
</tr>
<tr>
<td>MT Antenna Gain [dBi]</td>
<td>15 (900 MHz); 18</td>
<td></td>
</tr>
<tr>
<td>BS Antenna Gain [dBi]</td>
<td>2</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>Diversity Gain [dB]</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Interference Margin [dB]</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Power reserved for signalling and</td>
<td></td>
<td></td>
</tr>
<tr>
<td>control issues (Release 99 + HSPA) [%]</td>
<td>28.5</td>
<td>10</td>
</tr>
</tbody>
</table>

B. Results

Throughout this section, the main results are presented, with additional results being found in [14]. First, the results for single user scenario are analysed. The overheads considered are different for both systems and the throughputs analysed are the ones at application layer.

The different throughputs obtained in an indoor environment for different configurations are shown in Fig.5. This environment was chosen since the majority of users are within indoors when performing data services. Other environment considerations were performed also in [14].

SISO configurations present a lower range of achievable throughputs as expected, being also the ones that have a lower cell distance, considering the minimum throughput per configuration. These minimum throughputs are set by the system. Through the available models, the minimum throughput set was 2 Mbps, i.e., Release 99 DL maximum performance. With the use of SISO, the cell can go almost to 600 m, at the same time as in MIMO the range belongs up to 773 m, providing an increase of 29%, both performing with 64 QAM. It is shown that MIMO can perform lower throughputs, for higher distances and lower SNR comparing with SISO. One can observe from Fig.5 that in all modulations and configurations the maximum throughput is achieved over a distance greater than 100 m. Comparing the indoor situation with the other two environments, one can see that in the 64QAM SISO configuration, the vehicular environment can have cell radius 2.9 times and pedestrian environment 3.3 times more comparing with the indoor scenario.

In Fig.6 one shows the throughput variation according to three LTE possible deployment frequency bands. The system configuration uses a 20 MHz channel bandwidth, MIMO 4×4, 64 QAM in DL on a pedestrian environment. Despite the frequency band chosen, the same throughputs are achieved for the same SNR values but then for different distances, since different frequencies have different propagation conduct. The gap between the three bands is considerable. The 900 MHz band is the one who returns better coverage. For a minimum throughput of approximately 12.5 Mbps one has for 2600 MHz a maximum cell range of 0.42 km. With the use of 2100 MHz there is an increase of 39 % of cell radius, whereas with 900 MHz 3.5 times more cell radius is obtained for the same throughput. Also, in all frequency bands it is possible to achieve the maximum throughput considered beyond 100 m.

Since the penetration margins change with frequency, the differences perceived were higher for different environments. An additional perspective regarding the environment is shown in Fig.7, presenting the highest cell radius possible. At the 2600 MHz frequency band, with 20 MHz channel bandwidth, 64 QAM and MIMO 2×2, it is notable that a pedestrian scenario reaches a higher cell distance allowing an average increase of 47% and 3.5 times more radius comparing to vehicular and indoor scenarios. The cell edges were achieved for a minimum throughput of 7 Mbps. The different penetration margins provide the differences, as well as the slow and fast fading margins established. With the configuration chosen, in an indoor environment, for throughputs higher than 24 Mbps, the user has to be close to the BS in order to perform the connection.
LTE’s average user satisfaction grade is 0.86, while for HSPA+ is 0.78, reflecting that LTE users are served with closer throughputs from the ones requested. In addition, this grade is highly associated with the served users’ ratio, since the requested throughput cannot always be served, given the attenuation problems, such as fading or interference.

An analysis per service is performed in Fig.10, perceiving that LTE has higher delivered average throughputs than the ones obtained for HSPA+, due the superior capacity of LTE in order to serve more users with higher data rates. The same trend is found in the average service satisfaction grade, [14]. Some differences on throughputs per service are observed. Since Web and FTP are the most demanding services, requesting higher maximum throughputs possible, these services are also the ones that achieve higher average throughputs, 7.9 and 6 Mbps for LTE and 6.2 and 4.65 Mbps. Email is also affected by the same behaviour, although with lower requested throughputs. In order to differentiate these types of services, from the user’s viewpoint Web, FTP and Email are not throughput upper limited, i.e., they consume as much resources as possible to assign. The nature of the protocols renders the fact that more throughput leads to a better connection, hence, a better service.

‘Busy Hour’ analysis is presented in Fig.11, showing the number of served users and the total traffic consumed in an hour. LTE can perform approximately more 150 GB of data traffic in an hour than HSPA+, leading to an increase of 57%, serving almost 345 000 users compared to approximately 260 000 for HSPA+. The total network traffic depends essentially on the number of users performing in an hour, and the traffic percentage served over the same period. Besides the large covered areas from HSPA+, LTE serves more users over time.

An extended study was performed and additional DL results for complete parameters variation are presented in [14].

An UL analysis was also performed, with the metrics presented previously for DL achieving similar trends. Given that, UL results presented point to different situations. A
frequency scan was performed, as shown in Fig.12 presenting the averages network radius, and served users ratio.

![Figure 12. UL Averages Network Radius and Served Users ratio for different frequencies.](image)

It is noticed an increase of approximately of 173, 82, 64 and 134% of the average network radius, comparing with the 2.6, 2.1, 1.8 GHz and 2.1 GHz HSPA+ band. The same behaviour is observed on the average served users’ ratio, being LTE capable of serving more users resultant of higher capacity already shown in DL. One can say that, more covered users by LTE have SINR values above the threshold for the minimum throughput, compared with HSPA+. Note the identical served users’ ratio ranging from 1.8 GHz and 2.1 GHz, characterized by a higher standard deviation at the former frequency band, as it was observed in DL, [14]. From HSPA+, the increase of served users is approximately 45% compared with 2.1 GHz LTE, distinguished from the 15% increase in DL.

UL has a lower performance as expected when compared with DL results. MT limitations, namely noise figure, and power issues lead to some of the global differences gathered.

In Fig.13 one presents the averages network throughput and percentage of covered users. The differences are noticeable, with 7.81% more covered users for HSPA+ than LTE over 2.1 GHz, supported by a larger network radius. Even so, among the several LTE frequencies, 900 MHz is able to cover 25.5% and 17.6% more users than 2.1 GHz for LTE and HSPA+ respectively, where the difference between the 1.8 and 2.1 GHz is 3.5% less users for the higher frequency. Comparatively in UL, this distribution diverges faster than the one achieved in DL.

![Figure 13. UL averages Network Throughput and percentage of Covered Users for different frequencies.](image)

Concerning the average network throughputs, sole the increased performance of LTE at the same frequency of HSPA+, offering more than the double of the throughput, with 2.01 Mbps for the later and 4.34 Mbps for the former. It is also shown that with the decrease of frequency the average network throughput raises significantly, e.g., the difference between the two extreme frequencies analysed is 47%, with a highest average network throughput of 7.19 Mbps.

The lowest frequencies are able to cover more users; therefore, a greater ratio is also served contrasting with highest frequency bands, Fig.12. The 900 MHz has an average network throughput 138% higher than the 2100 MHz, and the 2600 MHz has 21% less. With the increase of the network radius and covered area at the 900 MHz band, there are users taking advantage of the network capacity, from the raise of the average network throughput delivered. Note the difference between LTE 2.1 GHz and HSPA+, which traduces the same trend analysed in DL, with a difference of almost less 9% of covered users for LTE.

The same channel bandwidth was set for both technologies. For an equivalent comparison, 5 MHz could be set as well for the default scenario, however, LTE is intended to use mostly larger bandwidths than UMTS (which also will perform in dual-carrier bandwidth), concerning the possibility of adjusting the channel bandwidth regarding planning purposes and the spectrum available for the operator.

One shows in Fig. 14 both averages network radius and served users ratio for HSPA+ and LTE with 5 MHz channel bandwidth. LTE radius increases with the decrease of the bandwidth for 5 MHz, resulting in link budget improvements from less noise resultant for the less applied RBs, hence, higher BS’s radius. Also note that multi-carrier systems like LTE improve over noise power compared with SC ones, given CP considerations on channel bandwidth. Over the same bandwidth circumstances, LTE reveals to define cell edges 10 m farther than the ones get from HSPA+, leading to an increase of 7%.

Still, this difference does not produce major changes in the ratio of covered users, being practically identical on both systems, such as the served users ratio presented in Fig.14 b). On the other hand, With the use of a lower bandwidth system resources are also fewer, compared to the ones available at higher bandwidths, so that LTE ratio of served users decreases 17% from the default scenario considering the same number of users.

From Fig.15, one shows the better LTE performance tendency over HSPA+. The average throughput obtained is 2.8 Mbps, against 1.99 Mbps obtained for HSPA+, being also 24% lower than the one obtained with the use of 10 MHz channel bandwidth, [14]. Globally, LTE’s standard deviation achieved is higher compared to the one achieved for HSPA+. The difference is explained by the models and the interpolation error associated, higher on LTE. The achieved average satisfaction grade leads to an increase of 8% for LTE, supported by the same reasons for DL, and reinforce the fact that LTE is still capable of deliver higher throughputs.
IV. CONCLUSIONS

This paper addresses a comparison between HSPA+ and LTE when deployed throughout two different approaches, focusing coverage and capacity aspects. The calculation of maximum cell radius, average network throughput and total network traffic are some of the outputs from both implemented models under similar conditions.

As expected in a single user viewpoint, one can conclude that for all the environments considered for DL and UL, the cell radius decreases with the increase of the throughput because higher throughputs require higher SNR values, which leads to a decrease of the path loss and a reduction of cell radius. For an indoor environment, regarding DL in HSPA+ with 64 QAM and MIMO 2×2, the cell radius varies from 0.773 km, for 2.0 Mbps, to 0.116 km, for 35.0 Mbps, which represents a decrease of 84%. Among different configurations, it was observed that LTE cell edges vary according the system parameters. Normally, LTE cell radii are shorter than the HSPA+ ones, the differences being explained by a higher throughput range. For instance, the maximum cell radius calculated for pedestrian was 0.419 km, while for indoors was 0.118 km at 7 Mbps.

Comparing HSPA+ with LTE in the multiple users’ scenario for DL, one shows that HSPA+ covers a large number of users than LTE presenting a higher average network radius. The average network radius for HSPA+ is 0.324 km, and for LTE is 0.230 km. LTE has an average ratio of served users 6% higher than the HSPA+ with an associated average satisfaction grade of almost 0.87, 9% higher than the one observed for HSPA+. Since the trade-off between covered average satisfaction grade of almost 0.87, 9% higher than the one achieved by HSPA+. Still, the average network throughput is 44% higher than the one delivered by HSPA+, however, with less available resources comparing with larger throughputs. These facts lead to a further user’s LTE satisfaction, about 8%, getting less reduced or delayed, receiving throughputs closer to the ones requested comparing with HSPA+, underlining the higher LTE’s performance shown, however, for some evaluated conditions the differences do not lead to the greater differences expected from theory. Currently upgrades from HSPA to HSPA+ are being carry out, while LTE brings a new complement to HSPA+, with optimised OFDMA solutions, designing an evolution path around both technologies which will not compete in the long term, but will complement each other.

REFERENCES