Analysis of Technologies for Long Term Evolution in UMTS

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***Abstract* — This paper studies LTE technologies in terms of capacity and coverage. For this purpose, a single user model was developed, estimating the maximum cell radius considering one user performing services. Also, a multiple users and multiple services scenario model was developed, as a more realistic approach. The results from the single user model show that for indoor environments the radius, in DL, is 0.16 and 0.09 km for the low and high losses one, for 10 MHz, UL radii being on average 65% lower. The multiple users' scenario shows an average cell radius of 0.21 and 0.11 km for DL and UL, respectively.**

I. Introduction

Wireless communications are, by any measure, the fastest growing segment of the communications industry. As such, it has captured the attention of the media and the imagination of the public. Cellular systems have experienced an exponential growth over the last years. Indeed, cellular phones have become a critical business tool and part of everyday life in most developed countries, as they are rapidly supplanting the old wire line systems. The explosive growth of wireless systems coupled with the proliferation of laptop and palmtop computers indicate a bright future for wireless networks, both as stand-alone systems and as part of the larger networking infrastructure. However, many technical challenges remain in designing robust wireless networks that deliver the performance necessary to support emerging applications [1].

By the end of 2004, 3GPP, under the need for 4th Generation (4G) requirements, took the initiative to define a radio interface that was based on the latest developments. This was labelled "Long Term Evolution" (LTE), also referred to as Super 3G, and is being specified as part of Release 8, further pushing radio capabilities higher, allowing an upgrade of UMTS to 4G mobile communications technology [2]. Releases 7 and 8 solutions for HSPA evolution are worked in parallel with LTE development, and some aspects of LTE work are also expected to reflect on HSPA evolution. The fundamental aims of this evolution will be met through improved coverage and capacity, improving data rates and reducing latency, to further improve service provisioning and reduce user and operator costs. LTE targets have more complex spectrum situations and also fewer restrictions on backwards compatibility. To support the new packet-data capabilities provided by the LTE radio interface, an evolved core network has been developed. The work on specifying the core network is commonly known as System Architecture Evolution (SAE). Release 8 was ratified as a standard in December 2008 [3].

Another standard that is emerging as a potential LTE alternative, developed by IEEE, is 802.16, also known as WiMAX, having the primary objective of making (fixed) broadband wireless access wider and cheaply available. Later, the original standard was enhanced so that improved radio features and support for mobility were addressed as well, known by Mobile WiMAX (IEE 802.16e) [4].

LTE multiple access is based on the use of Single Carrier – Frequency Division Multiple Access (SC-FDMA) with cyclic prefix in UL (uplink) and OFDMA in DL (downlink). In the design, physical layer parameter details have been picked in such a way that implementing multimode GSM/UMTS/LTE devices would be simpler, as well as facilitating the measurements to/from GSM/UMTS for radio-based handovers to enable seamless mobility. The fundamental difference to UMTS is now the use of different bandwidths, from 1.4 up to 20 MHz. Parameters have been chosen such that FFT lengths and sampling rates are easily obtained for all operation modes and at the same time ensuring the easy implementation of dual mode devices with a common clock reference. Shorter Transmission Time Intervals (TTIs), 1 ms, reduce the latency in the system, but add further demands on the Mobile Terminal (MT) processor. The smallest time-frequency unit for transmission is called a resource element, which is one symbol on one sub-carrier. A group of 12 contiguous sub-carriers in frequency and one slot in time form a Resource Block (RB).

The main purpose of this work is to study LTE and its impacts on a network, addressing coverage and capacity aspects. The objectives were accomplished through the development and implementation of a single user model, in order to evaluate the radius for this scenario and performing a first network coverage analysis; also a multiple users' model in a multiple services scenario was developed (closer to real network behaviour). Different bandwidths and MIMO (Multiple Input Multiple Output) configurations were compared, which has an enormous influence on network behaviour.

This paper has three more sections. The following one presents the theoretical model, while Section III addresses the analysis of results, and Section IV draws the conclusions.

II. Theoretical Models

To assess LTE DL and UL capacity and coverage, two models were developed: the single user and the multiple users ones. The former is intended to assess the maximum cell radius in such scenario, which can be used in the first phase of network planning to estimate cell radius, whereas the latter is intended to study DL and UL performance with the objective of analysing a more realistic scenario, with users performing multiple services, being randomly spread over the Base Station (BS) coverage area.

A. Single User

In the single user model, an evaluation of the maximum cell radius is done, which is the maximum distance that allows the user to be served with the requested throughput when the user is alone in the cell. This model depends of several parameters, such as, frequency, bandwidth, modulation, and MIMO configuration, among others.

The path loss is calculated using the link budget detailed in [5], key expressions being presented in (1) and (2):

$$SNR_{[\mathrm{dB}]}=P_{Rx_{[\mathrm{dBm}]}}-N_{[\mathrm{dBm}]}=EIRP_{[\mathrm{dBm}]}-L_{p_{[\mathrm{dBm}]}}+G_{r_{[\mathrm{dB}]}}-L_{u_{[\mathrm{dB}]}}-N_{[\mathrm{dBm}]}, \quad (1)$$

where:

- SNR: signal to noise ratio;
- P_{Rx}: received power at receiver input;
- N: total noise power;

  $$N_{[\mathrm{dBm}]}=-174+10\,log\left(\Delta f_{[\mathrm{Hz}]}\right)+F_{[\mathrm{dB}]}+M_{I_{[\mathrm{dB}]}} \quad (2)$$

  where:
  - Δf: the bandwidths of the RB allocated for the user,
  - F: the receiver's noise figure;
  - M_I: is the interference margin.
- $EIRP$: equivalent isotropic radiated power;
- G_r: receiving antenna gain;
- L_u: user losses.

From the COST-231 Walfisch-Ikegami propagation model, the cell radius can be calculated by [5]:

$$R_{[km]}=10^{\frac{EIRP_{[\mathrm{dBm}]}-P_{r_{[\mathrm{dBm}]}}+G_{r_{[\mathrm{dBi}]}}-M_{[\mathrm{dB}]}-L_{tt_{[\mathrm{dB}]}}-L_{tm_{[\mathrm{dB}]}}-L_{0_{[\mathrm{dB}]}}}{20+k_d}}, \quad (3)$$

where:

- L_{tm}: approximation for the multiscreen diffraction loss;
- P_r: available receiving power at the antenna port;
- M: total margin, described in [5];
- $L_{tt}^{'}=L_{tt}-k_d\cdot log_{10}\left(d_{[\mathrm{km}]}\right)$;
  - L_{tt}: rooftop-to-street diffraction loss;
- k_d: dependence of the multiscreen diffraction loss versus distance;
- d: distance between the user and the Node B;
- $L_0^{'}=L_0-20\cdot log_{10}\left(d_{[\mathrm{km}]}\right)$;
  - L_0:free space loss.

Some of the simulated frequencies exceed the frequency of the propagation model, and some of the obtained cell radii are below the minimum distance range, namely for high data rates. Nevertheless, the model was used, although a larger error may be expected.

B. Multiple Users

The multiple users simulator was adapted from the one developed in [6] and [7]. New LTE DL and UL modules were added, and the main structure had minor changes. Through a snapshot approach, these two modules analyse network capacity and coverage, calculating network parameters such as average radius, and number of users per BS. First an analysis in the BS level is performed, for all BSs. After obtaining the parameters for each BS, these modules compute averages, and extrapolate traffic and number of users per hour, for the busy hour.

The BS coverage radius is defined by the reference services, since in the single user model to each throughput corresponds a maximum distance, the coverage radius being calculated for two reference services: one for the city centre and another for all the remaining parts of the city. This approach was taken in order to obtain better coverage in areas with a lower number of BSs, [5]. The Relative MIMO Gain (RMG) model, [8], was applied to predict the improvements in capacity of using 2×2 and 4×4 MIMO over SISO. Regarding antennas power feeding, two approaches were taken: one assumes the same feeding power for all antennas, as for SISO; another, contrary to the first one, considers that the overall power available for the SISO system is equality split among all antennas.

One of the main differences between the two scenarios is that, for the multiple users' scenarios, the resources available in each BS are shared among all users, therefore, requiring the need to account users' interference through the introduction of the interference margin. Also for a more realistic approach, statistical distributions for the fading margins were considered and AMC (Adaptive Modulation and Coding) was also implemented.

The cell radius in the multiple users model is defined differently from the one used in the single user model: it is the distance of the user served further away from the BS. One should mention that the capacity also limits the cell radius, since when bit rate reduction strategies are executed, users further away from the BS have a higher probability of being delayed, leading to a reduction of the BS cell radius.

III. RESULTS ANALYSIS

A. Scenarios

The environments considered for both scenarios are pedestrian, vehicular, and indoor with low and high losses, [5]. These environments are distinguished by the different values of the slow and fast fading margins, as well as the extra penetration attenuation that differentiates the indoor low loss from the high loss environment. For the multiple users scenario, indoor environments represent the largest percentage of overall users, as it is, at the present, the most common environment for users performing the types of services analysed (data), mainly associated to laptops.

The single user scenario considers that there is only one user in the cell, therefore, all the available resources are allocated to this user. This scenario is used to calculate the maximum cell radius for the chosen throughput. In the multiple users scenario, one considers that users are uniformly distributed along the coverage area of the BS, performing different services with different bit rates.

For the multiple users scenario, seven services with different QoS classes. The penetration percentages, as well as the QoS priority, according to which services bit rates are reduced, are presented in Table I. For the QoS priority list, the first services to be reduced are the ones with higher QoS priority value. The maximum throughput values for the services considered in the default multiple users scenario in UL and DL are also presented in Table I.

Table I
Penetration, QoS Priority and maximum throughput.

Service	QoS		Maximum Throughput [Mbps]	
	Penetration Percentage [%]	Priority	DL	UL
Voice	5	1	0.064	0.064
Web	44.08	2	7.2	3.6
P2P	40.185	7	3.6	3.6
Streaming	5.89	3	3.6	0.512
Chat	2.945	6	0.384	0.384
E-mail	0.95	4	3.6	3.6
FTP	0.95	5	21.5	3.6

The parameters for the link budget evaluation and the default values are in [5], as well as the traffic models characterisation. For UL, the same traffic models cannot be used for all services, due to the asymmetry of some services.

B. *Single User Results*

Fig. 1 shows that when the bandwidth increases, the radius decreases: the increase of the bandwidth implies the increase of the total noise power, hence, SNR decreases, leading to lower radius. In a single user scenario, all RBs are allocated to the user to obtain the maximum throughput, so with the increase of the bandwidth the available RBs also increase, together with the maximum throughput.

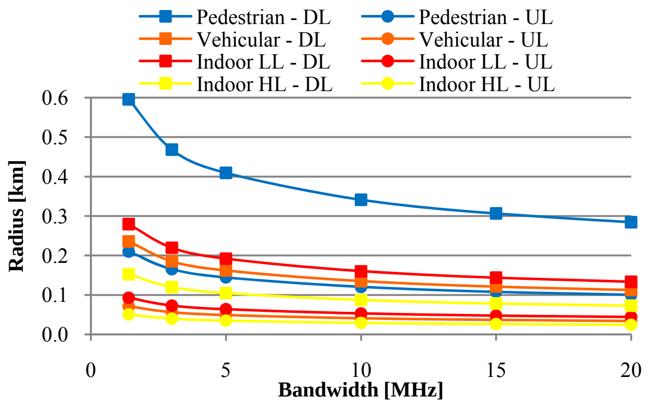

Fig. 1. DL and UL cell radius for 16 QAM, considering bandwidth and environment.

Considering the different environments, one can observe that the pedestrian one presents a higher cell radius, compared to the others. The pedestrian environment has lower attenuation margins, which leads to higher cell radius, since the sum of the three margins is considered in the path loss. This explains the similarity of the results for the vehicular and the indoor low loss environments, even though these environments have different channel characteristics.

Considering all the results obtained in this analysis, one notes that UL has lower radius than DL, and since the two links are deployed together, UL is the link that will limited the system in coverage issues. A lower frequency band can resolve the coverage issue in high traffic areas, and also decrease the number of BS that must be introduced in the network in order to resolve the coverage problems.

C. *Multiple User Results*

In the multiple users' simulator, several parameters were evaluated. The parameters chosen to analyse both links capacity and coverage were average network throughput and the average cell radius.

With the increase of the bandwidth, the number of RBs also increases, and so does network capacity. Fig. 2 shows the increase of the average network throughput with the increase of bandwidth, as expected. The slope is decreasing with the increasing bandwidth, i.e., the network will profit less and less with the increasing of the RBs in the bandwidth and the average network throughput does not increase so much. This can be explained by the BSs outside the high traffic area that do not have enough users to benefit from RBs increase with the bandwidth. So for higher bandwidths, some waste of capacity may occur in low traffic areas.

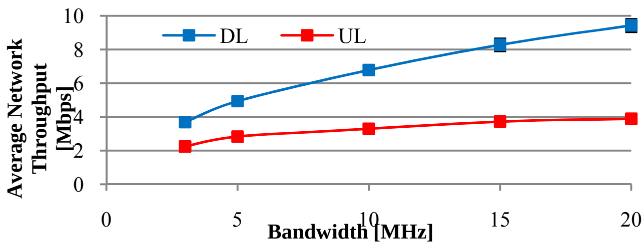

Fig. 2. DL and UL Network Throughput for the bandwidths of 3, 5, 10, 15 and 20 MHz

These parameters have a similar behaviour with the bandwidth in UL and DL, but in DL the network profits more from the capacity, since the increase of the average network throughput with bandwidth is higher. Network throughput values are higher for DL, but it is important to point out that the coverage area is 50% lower in UL, so there are less users to be served and consequently network throughput decreases. The average network radius does not have significant variations, which means that it can be considered constant for the different bandwidths.

The reduction of the frequency band to the 900 MHz band leads to an increase of the average network radius. This increase is due to the propagation behaviour, which depends on frequency. There is also the fact that in the 900 MHz band, the penetration margins are lower, so indoor users and vehicular ones, which correspond to 90% of the total, have lower penetration margins. From Fig. 3, one can observe that in the 900 MHz band the radius has an increase of 50% over 2100 MHz ones. When frequency increases to 2600 MHz, the average network radius decreases 17%, due to the increase of the propagation losses, since penetration margins are equal for the two frequency bands.

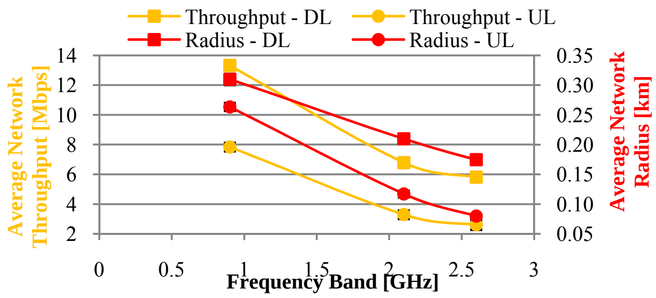

Fig. 3. DL and UL Network Radius and Throughput for the frequency bands of 900, 2100 and 2600 MHz

Concerning the average network throughput, 900 MHz is the frequency where is possible to serve more users and also serve users with a higher order modulation, it being 97% higher than the average network throughput in 2100 MHz, decreasing 14% to the 2600 MHz network throughput

From the default scenario, 2×2 MIMO and dedicated antenna power fed, the MIMO configuration was varied to 4×4 and, separately, the antenna power feeding to split. Changing the MIMO configuration, the number of antennas in the MT and BS rises to the double, from 2 to 4, and changing the antenna power feeding to split decreases to half the power of each BS antenna, since the analysis is in DL, meaning that the same power that feds the antenna in a SISO configuration will fed the antennas in a MIMO configuration. As expected, it is possible to observe, from Fig. 4, that 4×4 MIMO is the configuration that has the best performance. The average network throughput behaviour is explained by the need of lower SNRs that 4×4 MIMO needs, compared to 2×2, to achieve the same throughput. On the other hand, when the power antenna feeding is changed to split, higher SNRs are needed to achieved the same throughput than in a dedicated one, since the power of each antenna is reduced to half. The 4×4 MIMO has an increase, from the default scenario, of 45% in the average network throughput. Concerning the power antenna feeding, the split configuration has a decrease of 10% in network throughput. UL has a variation similar to DL, but with lower values and variation, being the increase of capacity due to 4×4 MIMO less notice. The split power fed has a decrease from the dedicated one of 8% and using 4×4 MIMO gives an increase of 30% compared with a 2×2 MIMO.

It is important to notice that in UL the use of split antenna power fed represents a capacity increase to SISO with no battery assumption increase, since the antennas in MIMO are fed with the same power that in a SISO configuration, as desired.

Additional results for DL and UL, regarding the default scenario, as well as the results for the other analysed scenarios, namely for the variation of some parameters (e.g., number of users and their profiles), and the analysis for the other calculated parameters, such as covered area, satisfaction grade, and average number of RBs, among others, are presented in [5].

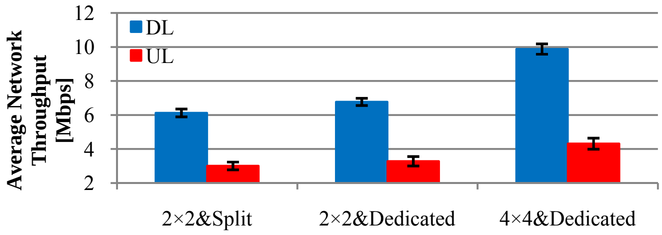

Fig. 4. DL and UL Network Throughput for the MIMO and antenna power fed variation

IV. Conclusions

This paper deals with the analysis of LTE, focusing on capacity and coverage aspects, as the number of user offering traffic to the network and services' penetration for both links. A simple theoretical approach is taken, enabling the calculation of the maximum cell radius in a single user scenario.

The results for the multiple and the single user models show that DL has a larger cell radius than UL, around 45%, the latter being the one that limits coverage. To increase coverage, a lower frequency band is desirable, since it is the factor with more impact on the radius, approximately 50 and 125% in DL and UL, but it also has a high impact on network capacity, since it is possible to serve more users with a higher order modulation. Focusing on the new technologies brought by LTE, 4×4 MIMO increases the capacity of the network, which leads to an increase of the average network throughput and of served users with higher satisfaction grade, since the network radius has just an increase of 10%. Having MIMO with split power feeding reduces the cell radius, around 10%, and an expected decrease of 10% in the average network throughput is observed. The increase of the bandwidth has it major impact in the high traffic areas, where the offered traffic exceeds the BS capacity.

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