LTE Radio Planning in Rural Environment

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Abstract

The work developed in this dissertation focuses on the planning of a mobile communications system with LTE (Long-Term Evolution) technology, for a specific area from Alentejo North, in Portugal, more specifically between the towns of Alandroal and Elvas, since LTE is currently the technology with the best performance, due to its capacity and low latency, and which will make the bridge to the transition to 5G.

This dissertation has the objective of applying a theoretical planning study, through several indicators of the area under analysis, such as land profile or population density, to a planning tool developed by Forsk, Atoll, in order to analyze the final results obtained through this one, after propagation models and equipment characteristics to be used in the simulations are chosen.

For the planning of this project were simulated the results for the LTE bands of 800 MHz and 1800 MHz, with bandwidths of 10 MHz and 20 MHz, respectively, after a previous analysis of the area under study and the potential number of users. Finally, was made a comparison between the results obtained, for the different indicators under study, with the theoretical results previously calculated.

Keywords**:** Mobile Communication, LTE, Radio Planning, Carrier Aggregation, Coverage, Capacity

I. INTRODUCTION

The way people communicate today has been changing during the past decade, leading mobile networks to an intense growth and an exponential increase in traffic associated with user demand and also the increase in population density in urban areas, being expected the in the next years this growth will continue to present a trend that until then (Figure 1).

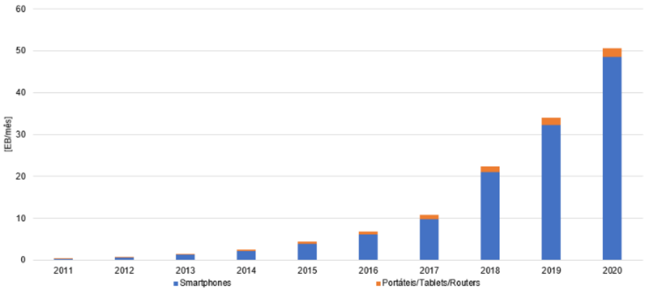

Figure 1: Evolution of mobile traffic on mobile devices [1].

The traffic growth, specially in data traffic, is mainly due to an increase in the number of applications available to users, driven by the smartphones, such as social networks, online games or video streaming. This increase was possible by the transition from previous technologies to the fourth generation (4G) or LTE (Long Term Evolution), presenting itself as the most mature and advanced technology, compared to its predecessors, at various levels such as latency and bit rate [2]. This technology operates with different bandwidths and in different areas of the radio spectrum, being able to occupy areas of the spectrum previously used by GSM or UMTS through a refarming process (reuse of spectrum areas, which were initially assigned to a certain technology, in a way to be used in a technology other than the initial one). With the evolution of LTE to LTE-Advanced, it was possible to obtain throughput values in the order of 300 Mbps, reaching up to 600 Mbps with certain features, and in recent years, with the beginning of the partnership between 4G and 5G, it was possible to obtain values throughput greater than 1 Gbps [3].

II. STATE OF ART

A. LTE

LTE arises with the demand from mobile networks users for an increasingly high bit rate to turn possible to enjoy all the functionalities of the mobile equipments, in case of leisure or professional level.

1) Bit rate

With LTE, it was able to overcome the bit rate values provided by UMTS (3G), achieving values greater than 100 Mbps in the downlink and 50 Mbps in the uplink, with low latencies (10 ms) and a bandwidth range from 1.25 MHz to 20 MHz [4].

The bit rate can be calculated using (1), with N_{BR} as the number of resource blocks per subframe, N_{SP} as the number of subcarriers per resource block, $N_{bits/simb}$ as the number of bits per symbol, N_{simb} as the number of symbols per subcarrier, Cod as the encoding rate, $N_{streams}$ as the MIMO configuration and $D_{subframe}$ as the subframe duration.

$$R_b = \frac{N_{RB} \times N_{SP} \times N_{bits/simb} \times N_{simb} \times Cod \times N_{streams}}{D_{subframe}} \qquad (1)$$

2) Modulation

Once data signals are emitted in low frequencies, they always need to be “transported” by an high frequency, called carrier, to be able to be sent to a distant receiver, where they are later demodulated to obtain the initial message. This process is called modulation. In this way, the information is modulated in the transmitter, sent through the proper channel to the receiver, where the demodulation is carried out.

With LTE it’s possible to use an higher order modulations (more data bits per modulation symbol), namely, QPSK, 16-

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QAM, 64-QAM and 256-QAM, contrary to those used until then in previous generations, with the aim of increase transmission rates. Through QPSK it is possible to guarantee a transmission of 2 bits per symbol, with 16-QAM 4 bits per symbol, with 64-QAM 6 bits per symbol and with 256-QAM 8 bits per symbol. With lower modulations, it’s possible to guarantee a more robust connection that withstands higher levels of interference without losing the connection but with a lower bit rate when comparing with higher modulations, which, in order to achieve higher bit rates, are sensitive to errors due to noise and interference [5].

The adaptations and modifications in the connections are carried out using the AMC (Adaptive Modulation and Coding) technique, selecting the modulation to be used through the value of the signal-to-noise ratio (SINR), calculated through the ratio between the average power of the signal and the sum of the existing interference power and noise. The higher the SINR value, the better the signal level and the transmission conditions, and a higher modulation such as 64-QAM or 256-QAM can be used, on the contrary, with low SINR it’s an indication of adverse propagation conditions or high distances between the transmitter and the receiver, which this last one may even be at the cell boundary, which leads to using a lower modulation such as QPSK that supports fewer bits per symbol in order to guarantee a stable connection with a lower error rate [6]. In this way, typically, the closer to the radio base station (RBS) the UE (user equipment) are, the better the SINR values will be, achieving in this way an higher order modulation and consequently better bit rates.

Encoding rates represent the ratio between the number of data bits and the number of bits encoded. Lower rates are used with lower SINR values while higher encoding rates are used with good radio conditions (high SINR values).

Through the CQI (channel quality indicator), which can vary between 0 to 15 (being lower as the transmission quality is lower in the downlink channel, as can be seen in Figure 2), sent by the UE to the eNodeB, it can determine which encoding rate is more appropriate to use so that the mobile device can decode the message with a BLER (Block Error Rate) below 10%.

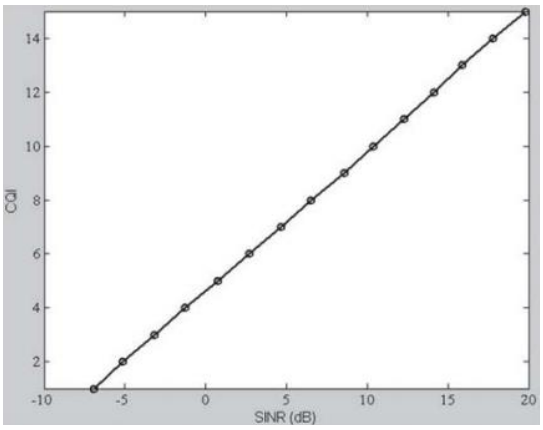

Figure 2: Mapping between CQI and SINR values [8].

In this way, the UE is able to inform whether it has a high signal quality and thus can receive an higher bit rate. Links with BLER values greater than 10% indicate an increase in packets with errors, leading to information retransmissions that lead to lower bit rates [9].

CQI Index	Modulation	Encoding Rate	Bits per Symbol	Efficiency (Enconding Rate x Bits/Symbol)
0	“Out of range”	-	-	-
1	QPSK	0,076	2	0,1523
2	QPSK	0,188	2	0,377
3	QPSK	0,438	2	0,877
4	16QAM	0,369	4	1,4766
5	16QAM	0,479	4	1,9141
6	16QAM	0,602	4	2,4063
7	64QAM	0,455	6	2,7305
8	64QAM	0,554	6	3,3223
9	64QAM	0,650	6	3,9023
10	64QAM	0,754	6	4,5234
11	64QAM	0,853	6	5,1152
12	256QAM	0,694	8	5,5547
13	256QAM	0,778	8	6,2266
14	256QAM	0,864	8	6,9141
15	256QAM	0,926	8	7,4063

Table 1: CQI table with respective modulation [7].

Considering then the different types of modulation and respective coding rates, described in Table 1, each one of them will correspond to an expected bit rate value, being the SINR value reported by the UE that makes the selection on which modulation to use.

The relation between bit rate and SINR can be established by the equation (2), being B the bandwidth and N the number of subcarriers per bandwidth [10]:

$$R_b = \frac{B}{N} \times \log_2(1 + SINR) \tag{2}$$

Through (2), the bit rate values were calculated as a function of the SINR for a bandwidth (B) of 20 MHz and the respective number of subcarriers (N), illustrated in Figure 3, and where it’s possible to verify that higher the reported SINR value, higher will be the bit rate available to the user.

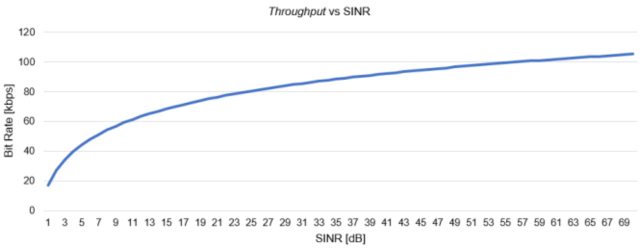

Figure 3: UE bit rate vs SINR.

3) LTE-Advanced and LTE-Advanced Pro

In order to improve the initial bit rate offered by LTE, LTE-Advanced emerged, being possible to use bandwidths of 100 MHz, MIMO up to 8x8, carrier aggregation (CA) and ComP (Coordinated Multi Point) [11].

a) MIMO

In order to guarantee higher bit rates, MIMO was designed, being a method to increase the capacity of a radio link by using multiple transmitters (Tx) and receivers (Rx) to obtain spatial diversity gains while explore multipath signal propagation [12]. Each transmitter sends the signal, using the same time and frequency resources, to all receiving antennas, which

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demodulates the information to correctly obtain the original message. In this way, in an environment with multiples obstacles between the transmitter and the receiver, it is possible to create multiple independent paths between them, achieving a higher information transmission rate, thus bypassing channels with possible problems with low propagation characteristics, interference and multipath, without the need to increase bandwidth and/or transmission power.

The bit rate is dependent on the MIMO system used, being linearly proportional to the minimum number of antennas used for transmission or reception.

There're 4 possible signal transmission and reception solutions (represented in Figure 4):

- SISO (Single Input Single Output) – initial and most basic solution where there's only one transmitting and one receiving antenna;
- SIMO (Single Input Multiple Output) – solution with one transmitter and two or more receivers. Due to there's only one transmitter in this solution, the bit rate will suffer no change, however coverage is improved;
- MISO (Multiple Input Single Output) – solution with two or more transmitters and one receiver. Since the signal is sent by all transmit antennas, the transmit diversity will increase, as well as signal quality in bad radio conditions. Although it doesn't increase the bit rate, it can offer the same bit rate with a lower output power;
- MIMO (Multiple Input Multiple Output) – solution which has a basic 2x2 MIMO configuration (2 transmitters and 2 receivers), but it can reach up to MIMO 8x8, with the signal transmitted by two or more antennas and demulated in the receiver, increasing the bit rate to double, quadruple or eightfold, depending on the configuration used.

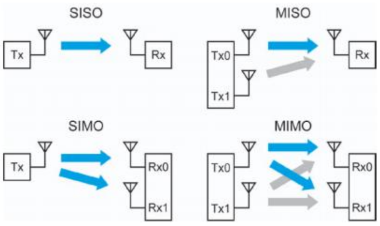

Figure 4: Transmission solutions [13].

b) Carrier Aggregation

With CA, it's possible to aggregate up to five carriers on the downlink, increasing the total bandwidth up to a maximum of 100 MHz, which leads to an increase in the throughput available to the end user. Each aggregated carrier is called component carrier (CC), which can have a bandwidth of 1.4, 3, 5, 10, 15, 20 MHz and, in the case of LTE-Advance Pro, 100 MHz.

The RRC links are managed by the primary component (pcell – primary cell) and all the others CC's are considered secondary components (secondary cells), with the objective of increasing the bit rate and used only for traffic, as shown in Figure 5.

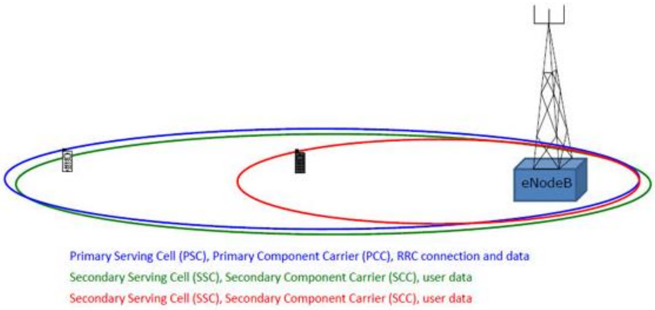

Figure 5: Carrier Aggregation – serving cells [11].

		UE Classes								
		1	2	3	4	5	9	11	12	16
Bit rate [Mbps]	DL	10	50	100	150	300	450	600	600	1000
	UL	5	25	50	50	75	50	75	150	150
Bandwidth		20 MHz								
Modulation		QPSK, 16 QAM		64 QAM					256 QAM	
MIMO		Optional	2x2			4x4	2x2 or 4x4			4x4
DL CC's		1					2 or 3	2, 3 or 4		3 or 4

Table 2: UE classes in LTE (adapted from [14]).

c) CoMP

To improve coverage in the eNodeB's coverage limits (cell edge), the CoMP was created. Its objective is to transmit and receive signal between different TX/RX (transmitter/receiver) belonging to the same or different eNodeB's in order to provide the best possible coverage between the different sectors and cells to the UE. As shown in Figure 6 and Figure 7, there are two ways to implement the CoMP feature, the first called "joint transmission" where the TX's transmit at the same frequency and subframe (Figure 6) and the second, "dynamic point selection" where each TX transmits in its own subframe (Figure 7).

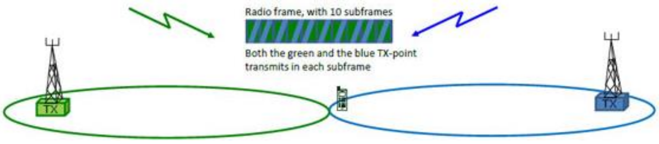

Figure 6: DL CoMP in joint transmission between two transmitters from different eNodeB's to the same UE [11].

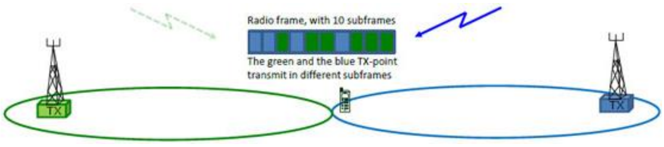

Figure 7: DL CoMP in dynamic transmission where each transmitter sends in different subframes to the same UE [11].

4) Link Budget

The link budget is based on the calculation of the propagation attenuation between the transmitter and the receiver. For this, is necessary to know the different characteristics between existing technologies and variables that may influence cell coverage, such as mountainous or water areas, equipment losses, antenna or amplifier gains and transmission powers.

When doing a network planning, it's essential to know the coverage area of each base station and how many of these are needed to ensure good signal quality and coverage of the area under analysis. In order to be able to determine the individual area of each radio base station and the distance between them, a simulation is done through propagation models, both for downlink and for uplink, knowing in advance the maximum attenuation values or the MAPL (Maximum Allowable Path Loss), which can be calculated through (3), with P_{TX} as transmission power, L_{TX} as transmission losses, L_{RX} as reception losses, S_{RX} as receiver sensitivity, L_{Prop} as signal propagation losses and G_{Ant} as transmit antenna gain [15].

$$MAPL = P_{TX} - L_{TX} - L_{RX} - S_{RX} - L_{Prop} + G_{Ant} \tag{3}$$

In a mobile network planning and in the calculation of the link budget, it's necessary to take into account that the more users a network has, higher will be the interference values due to the multiples connections to it and, consequently, the quality and performance of the network decrease. Since the transmission power is divided by the total number of RBs, could be considered an increase in power, however, it's not a viable solution, since it would introduce even more interference into the network.

One way to reduce interference, added into the network by users, is using a the "*cell breathing*" technique, illustrated in Figure 8, which allows load balancing between cells, where overloaded cells have the possibility of transferring users to neighboring cells, causing that its service area decreases and the neighboring cells increase [16].

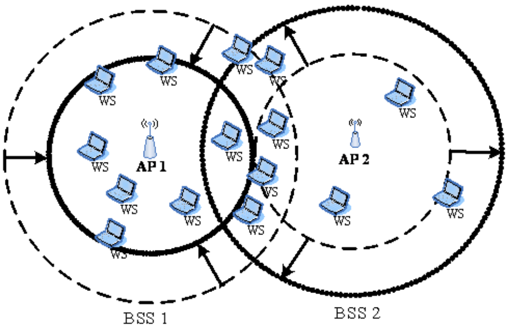

Figure 8: Cell breathing technique [16].

In order to represent the interference value inserted by users in uplink and downlink, it's possible to insert an interference margin (IM) in the calculations performed, through (4) and (5), respectively, with $SINR_{min}$ as the minimum SINR required for connection, Q_{UL} as the system load in uplink, F_c as the gain resulting from the variation of the antenna's electrical tilts, $P_{tx/RB}$ as the transmission power per RB, Q_{DL} as system load in downlink and TN as thermal noise:

$$IM_{UL} = 10 \log\left(\frac{1}{1 - SINR_{min} \times Q_{UL} \times F_c}\right) \tag{4}$$

$$IM_{DL} = 1 + \frac{P_{tx/RB} \times Q_{DL} \times F_c}{TN \times L_{Prop}} \tag{5}$$

To calculate the link budget in downlink and uplink we use (6), with L_{BL} as body loss, L_{CPL} as car penetration loss, L_{BPL} as building penetration loss, G_a as the sum of transmit and receive antenna gain, P_{AMP} as amplifier power, N_{RB} as the number of RB's in each symbol, NF_{RX} as receiver noise figure and B as RB bandwidth:

$$A = P_{TX} - L_{TX} - S_{RX} - MI - L_{BL} - L_{CPL} - L_{BPL} + G_a \tag{6}$$

$$P_{TX} = P_{AMP} - 10 \log N_{RB} \tag{7}$$

$$S_{RX} = NF_{RX} + TN + SINR_{min} \tag{8}$$

$$TN = -174 + 10 \log B \tag{9}$$

An important value to define the quality of the connection is the SINR (Signal to Interference plus Noise Ratio), being the ratio between the signal level and the noise (signal-to-noise ratio), measured in dB, calculated through (10).

$$SINR = P_{RX} - Noise - Interference \tag{10}$$

The higher the SINR value, the better the signal quality will be, and in this way it's necessary to ensure values above 13 dB because below this value the connection speed will be very low due to noise in the received signal or because the received signal strength is very low, leading to that the probability of the connection being dropped is high.

Radio Conditions	SINR (dB)
Excellent	>= 20
Good	13 a 20
Reasonable	0 a 13
Bad	<= 0

Tabel 3: SINR rating according to its value [17].

III. NETWORK PLANNING

A. *Coverage Planning*

A radio propagation model is characterized by being an empirical mathematical formulation, taking into account several aspects related to the propagation of radio waves such as frequency (Figure 9) or eNodeB height (Figure 10), with the purpose of predict the resulting losses of the signal path between transmitter and receiver. Signal propagation is directly affected by atmospheric conditions and terrain topography, so it's essential to use the proper propagation model.

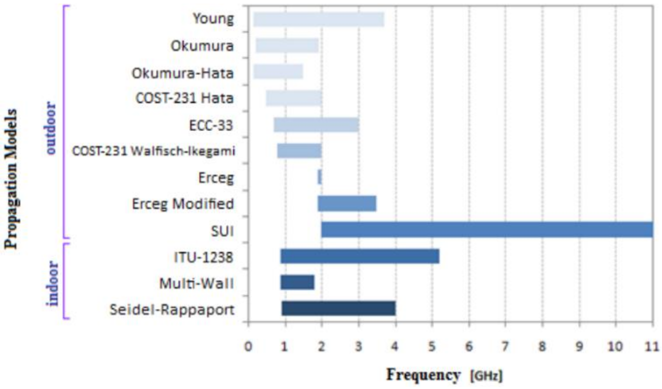

Figure 9: Propagation models as a function of frequency used [18].

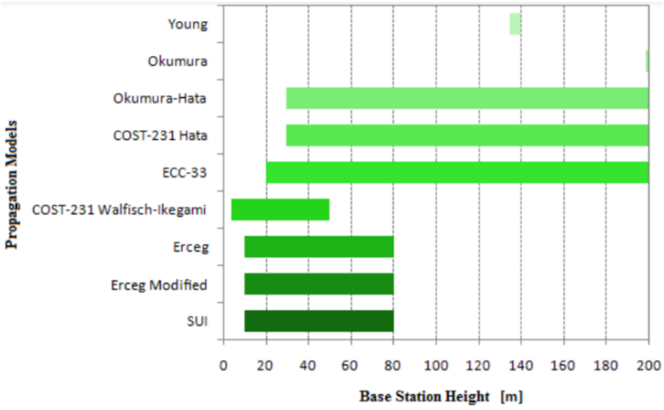

Figure 10: Propagation models as a function of base station height [18].

Propagation environments are divided into three categories: rural, suburban and urban. In each type of environment there are several factors to be considered when making a network planning, such as: height and density of buildings, density of vegetation, terrain profile (plain, valley, mountainous, watery…).

To obtain the value of path loss (PL) it's possible to use (11):

$$PL_{[dB]} = K_1 + K_2 \log d_{[Km]} \tag{11}$$

K_1 and K_2 are values dependent on the propagation model to be used and $d_{[Km]}$ the distance between emitter and receiver [19].

Depending on the transmission frequencies, we have the following propagation models, with $F_{[MHz]}$ as transmission frequency in MHz, H_t as transmit antenna height, H_r as receive antenna height and K_c as a morphological correction factor (value dependente on the propagation environment):

- For low bands (700, 850 or 900 MHz) the Okumura-Hata model is used:

$$K_1 = 69{,}55 + 26{,}16\log\left(F_{[MHz]}\right) - 13{,}82\log(H_t) - a(H_r) + K_c \tag{12}$$

- For frequencies between 1,5 GHz and 2,1 GHz is used the COST-231 Hata model:

$$K_1 = 46{,}3 + 33{,}9\log\left(F_{[MHz]}\right) - 13{,}82\log(H_t) - a(H_r) + K_c \tag{13}$$

- For 2,6 GHz a modified COST-231 Hata model is used, once this one is limited to frequencies above 2,1 GHz:

$$K_1 = 46{,}3 + 33{,}9\log(2000) + 20\log\left(\frac{F_{[MHz]}}{2000}\right) - 13{,}82\log(H_t) - a(H_r) + K_c \tag{14}$$

With:

$$K_2 = 44{,}9 - 6{,}55\log(H_t) \tag{15}$$

$$a(H_r) = 3{,}2(\log 11{,}75H_r)^2 - 4{,}97, \qquad K_c > -5 \tag{16}$$

$$a(H_r) = \left[1{,}1\log\left(F_{[MHz]}\right) - 0{,}7\right]H_r - \left[1{,}56\log\left(F_{[MHz]}\right) - 0{,}8\right], \quad K_c \leq -5 \tag{17}$$

$$K_c = 0, urban \tag{18}$$

$$K_c = -2\left(\log\frac{F_{[MHz]}}{28}\right)^2, suburban \tag{19}$$

$$K_c = -4{,}78\left(\log F_{[MHz]}\right)^2 + 18{,}33\log F_{[MHz]}, rural \tag{20}$$

Since bit rate and SINR values are also dependent on the cell radius, by manipulating (11), it's possible to determine the coverage radius by using (21):

$$d_{[Km]} = 10^{\frac{PL_{[dB]} - K_1}{K_2}} \tag{21}$$

B. *Capacity Planning*

Capacity planning allows to do a prediction of the resources needed to support the user traffic demand, with a pre-determined bit rate and QoS, satisfying the user needs, without reaching high network congestion levels, or in other words, not reaching the maximum limit of users in the network. Among the parameters necessary to determine, to guarantee a good experience for users, are the bandwidth, type of MIMO, antenna characteristics or modulation.

The population density, the total number of active users, combined with the type of density, distribution and traffic profile of these same users, in the area under study, are essential factors for a good capacity planning in order to ensure a good quality of service during periods of higher traffic or "busy hour" and to avoid overloading the network, allowing to scale the traffic offered in the cell to the existing demand made by users, during these periods.

The busy hour can then be characterized as the hour with the highest traffic in the cell or busy hour in the system, influencing directly the number of radio base stations and the quality of the service provided.

As mentioned, in a mobile network there are periods of the day where traffic loads are higher, as can be seen in Figure 11, where the hours of highest traffic are between 11:00 and 17:00, being processed about 56% of the traffic voice, more than half of the total traffic in a day in just 7 hours.

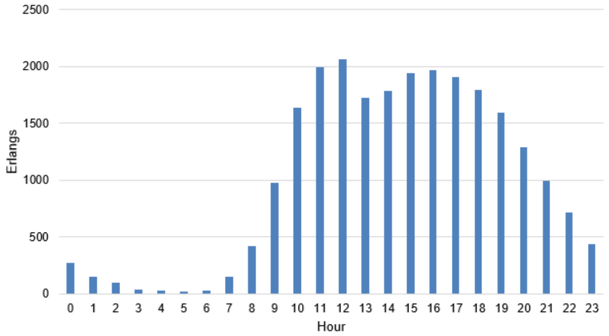

Figure 11: Daily voice traffic distribution (in erlangs) typical of a mobile network.

In this work we will study in detail the area between the town of Alandroal and Elvas, in Portugal's region of Alentejo North. Currently, a new railway is being built in this area, connecting to Spain, which will have to be taken into account in planning. In this way, it's necessary to ensure good values along zone 3 of the railway section between Évora and Caia, as shown in

Figure 12, and taking into account the nearby built-up areas, towns and their population density, the data from Table 3.3 was taken into account.

Figure 12: Section between Evora and Caia of the new railway [20].

Parameter		Value
Vertical Aperture Antenna [º]	LTE 800	15.4
	LTE 1800	6.6
Area [Km^2]		90
Population Density [in/Km^2]		23
Transmission Frequencies [MHz]		LTE 800 and LTE 1800
Bandwidth [MHz]	LTE 800	10 MHz
	LTE 1800	20 MHz
Terrain Morphology		Rural
Total Population [in]		2000
Sectors per eNB		2

Tabel 4: Characteristics, parameters and network equipment used in the coverage planning of the sudy area.

C. *Link Budget Calculation*

With the information gathered in previous chapters it was possible to make a prediction of the bit rate and SINR values. Through the parameters indicated in Table 5, the theoretical values for the bit rate, indicated in Table 6, were calculated.

Parameter		Value
Mobile Device		Huawei P30
Subframe Duration [ms]		1
MIMO	LTE 800	2x2
	LTE 1800	4x4
Number of bits per Symbol		8
Number of RB's per Subframe	LTE 800	50
	LTE 1800	100
Code Rate		0.926
Users		500

Tabel 5: Parameters used in theoretical calculations for the bit rate.

KPI	Direction	CC's Used	Theoretical Value
Total Bit Rate [Mbps]	Downlink	L800	118.69
		L1800	474.76
		L800 and L1800	593.44
	Uplink	L800	118.69
		L1800	237.38

Tabel 6: Theoretical values calculated of the bit rate.

After calculating the total bit rate values, taking into account the parameters in Table 4, it was calculated the bit rate per user, knowing the total users who may be connected to the network at the same time, with the values described in the Tabel 7.

KPI	Direction	CC's Used	Theoretical Value
Bit Rate per User [Mbps]	Downlink	L800	0,24
		L1800	0,95
		L800 and L1800	1,19
	Uplink	L800	0,24
		L1800	0,47

Tabel 7: Theoretical values calculated for the bit rate per user.

To calculate the theoretical SINR values, indicated in Table 10, it is necessary to define the path loss values, calculated by the parameters indicated in Table 8.

Parameter		Value
UE Height [m]		1.5
Log normal Fading [dB]		6
Noise Figure [dB]	LTE 800	2.1 – 2.2
	LTE 1800	< 2.4
eNB Antenna Gain [dBi]	LTE 800	15.3
	LTE 1800	17.1
UE Antenna Gain [dBi]		3
MHA Gain [dBi]		9.8
Interference Margin [dB]		1
Antenna Model		APXVBBLL15H_43-C-I20
MHA Model		FLPMDK triple band 700/800/900 dual MHA
Penetration Loss (rural) [dB]	LTE 800	5
	LTE 1800	8
Body Loss [dB]		1
eNB Transmission Power [dBm]		43
UE Transmission Power [dBm]		23
Thermal Noise [dBm]		-121.45

Tabel 8: Parameters used in the theoretical calculations of SINR.

Using the Okumura-Hata model for L800 band and the COST-231 Hata for L1800 band, was calculated the values for the path loss, described in the Table 9.

Parameter	L800	L1800
$\boldsymbol{PL_{[dB]}}$	157.09	147.80
$\boldsymbol{K_1}$	118.74	117.96
$\boldsymbol{K_2}$	38.35	
$\boldsymbol{a(H_r)}$	0.01	
$\boldsymbol{K_c}$	12.93	
$\boldsymbol{d_{[Km]}}$	10	6

Tabel 9: Theoretical values for the path loss in each LTE band.

KPI	Direction	LTE Band	Theoretical Value
SINR [dB]	Downlink	L800	20.31
		L1800	18.40
	Uplink	L800	14.30
		L1800	14.10

Tabel 10: Theoretical values obtained for SINR at cell edge.

D. *Electrical and Mechanical Tilt*

Tilt is the inclination, in degrees, of the antenna in relation to its referential axis, and an electrical or mechanical tilt can be done in order to direct the main lobe of the antenna to the areas it intends to serve, as illustrated in Figure 13, ensuring a stronger signal in areas of interest, or as an action in situations of interference or overlapping coverage with neighboring cells. If the antenna is tilted down (towards the ground), it is downtilted, otherwise it is uptilt.

- Electrical tilt (ET) – tilt done by changing the characteristics of the input signals in the antenna, more specifically its phase, causing a change in the radiation diagram and consequently all the radiation lobes suffer changes. The tilt can have a fixed or variable value, and in case of variable, the change can be done directly on the antenna in the field, manually adjusting the screw, that regulates the tilt value from a range of values predefined by the manufacturer, to the desired value, or it can be done remotely through a remote electrical tilt (RET), in which the change is made by the engineer remotely, through a motor that controls the screw, which can be installed outside the antenna or within it;
- Mechanical tilt (MT) – a mechanical tilt is a physical change made directly to the antenna, tilting it to the desired inclination with proper accessories to support it, without changing the input signal, causing the radiation lobes to maintain the same profile but pointing in diferente directions. This tilt value is limited by the extendable supports placed between the antenna and the mast that supports it, the support can be placed on top of the antenna for downtilt or at the bottom for uptilt.

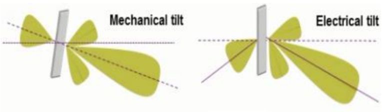

Figure 13: Radiation scheme with mechanical and electrical tilt (adapted from [21]).

In network planning and optimization, it is typically preferable to use the electrical tilt rather than mechanical tilt, since the latter when applied, for example in downtilt, can cause a negative impact with the rear lobes in the network, which can lead to an increase of interference, which does not occur with an ET where the entire signal is concentrated closer to the antenna. In this way, whenever possible, the electric tilt is used and only when it reaches its maximum or minimum value, pre-defined in the technical sheet of the antenna, is it considered to perform a MT.

The total tilt value of an antenna can be obtained by (22), adding the electrical (α_{elec}) and mechanical (α_{mech}) tilt:

$$\alpha_{tilt} = \alpha_{elec} + \alpha_{mech} \tag{22}$$

The location and orientation of the sectors for both radio base stations were specifically planned to cover the entire length of the study area and in order to reduce costs of support structures (such as telecommunications towers, once the higher they are the higher their installation costs) by making the installation in places with high elevations such as hills.

For a correct estimate of the tilt values, it's necessary to know the altitude values of the transmitter and receiver terrain and the distance between them, as well as the height at which the antenna will be installed (height of the telecommunications tower or height of the building, in case of installation in rooftop), as illustrated in Figure 14.

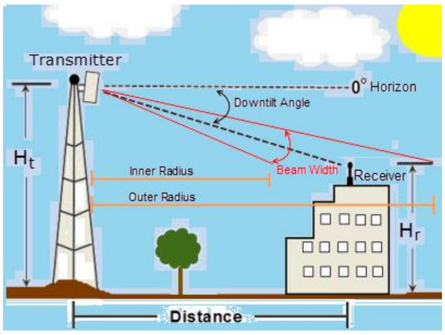

Figure 14: Schematic between the various factors involved in the tilt calculation [22].

$$\alpha_{tilt} = \tan^{-1}\left(\frac{H_t - H_r}{d}\right) + \frac{\alpha_{av}}{2} \tag{23}$$

Through (23), the values for the tilts to be used were calculated, as described in Table 11, being after adjusted according to the area under analysis and the locations of the radio base stations, represented in Figure 15:

eNodeB Code	Band	Sector	Azimuth [°]	Antena Height [m]	MT [°]	ET [°]
RBS1	L800	1	65	10	0	5
		2	260	10	0	5
	L1800	2	260	10	0	3
RBS2	L800	1	50	10	0	5
		2	210	10	0	5

Tabel 11: Tilt values for the different cells planned for the study area.

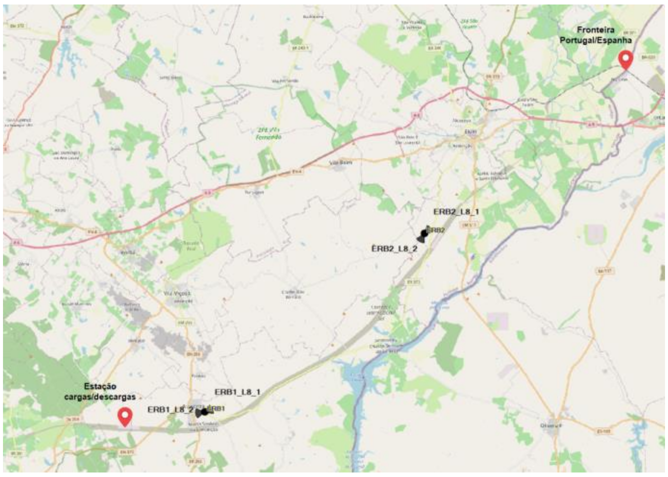

Figure 15: Area under study – rural area between the town of Alandroal and the border between Portugal and Spain, with future railway being taken into account.

IV. RESULTS ANALYSIS

After configuring in the planning tool "Atoll" all the necessary inputs, presented in the previous chapter, such as the antenna model and its gain, emitted power or RBS height, were obtained the results described in the following chapters.

A. RSRP

RSRP – Reference Signal Received Power – indicates the values of the average power of the reference signal received in the UE for a specific bandwidth. The values for this indicator are typically between -44 dBm and -140 dBm, described in Table 12.

Radio Conditions	RSRP (dBm)
Excelent	>= -80
Good	-80 a -90
Fair	-90 a -100
Cell Edge	<= -100

Tabel 12: RSRP rating [23].

After simulation, were obtained the results represented in Figure 16, guaranteeing values of at least -110 dBm at cell edge, along the entire section under study, in theory enough to maintain a voice call if necessary, although low values to maintain a data session with high bit rates. For the town close to RBS1 (Alandroal), served by its second sector, there are excellent RSRP levels, always above -70 dBm, ensuring good quality and throughput values.

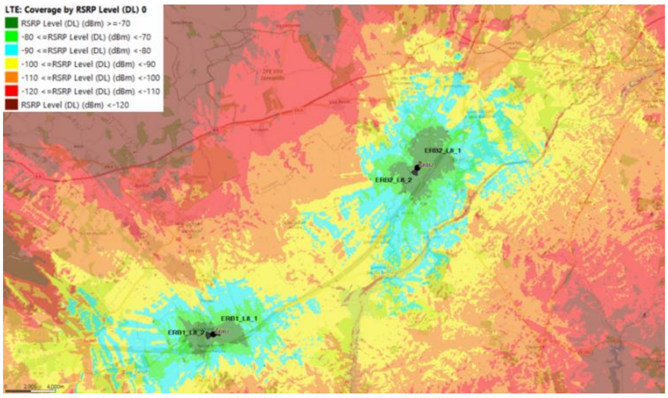

Figure 16: RSRP obtained by simulation [24].

B. Best Server

With the best server simulation, illustrated in Figure 17, it's possible to see that in all sectors the L800 serves as the best server, with a well defined border between sector 1 of RBS1 and sector 2 of RBS2 of L800. However, there are some areas at the cell edge, in which the RSRP values are smaller, where alternate best server zones are verified, always serving the cell with the best received signal level. Once the L800 was defined as primary cell, to avoid pcell swaps on the coverage border of the L1800 cell, the simulation are according with the planned.

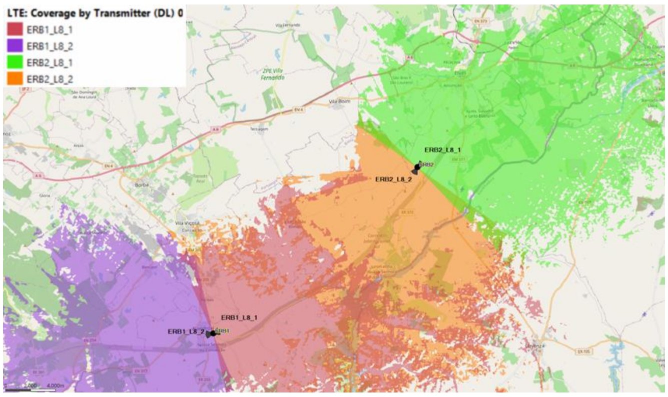

Figure 17: Best Server's obtained by simulation [24].

C. Quality

1) SINR

The SINR directly influence the maximum bit rate, once the higher is this indicator, the better the network performance will be, since higher order modulations can be used.

In the simulation obtained, represented in Figure 18, it is possible to verify that SINR values, throughout the extension of the area under analysis, are always higher than at least 17 dB, which allows users to be able to use the network features with a good quality even in cell boundary zones.

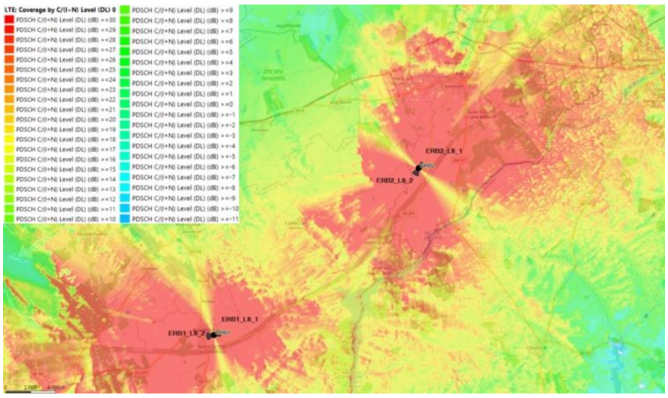

Figure 18: SINR obtained by simulation [24].

2) BLER

Since the SINR values are quite favorable in the study area, the simulated rate of wrong received blocks on the mobile device is quite low, as expected, being very close to 0% near to the radio base stations and around 5 %-10% in the remaining areas. Taking into account that the BLER must present values below 10%, the results obtained by simulation and illustrated in Figure 19, presents very beneficial values for a good quality in the mobile network.

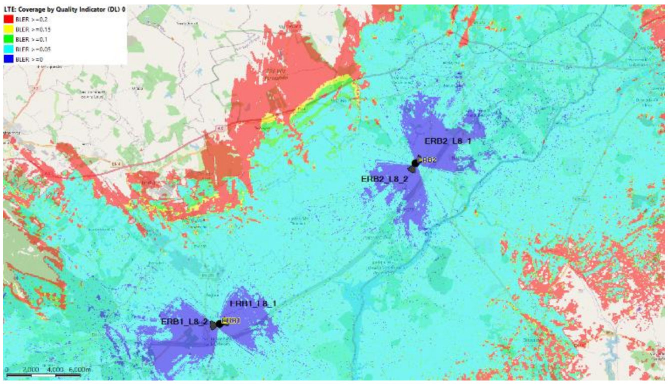

Figure 19: BLER obtained by simulation [24].

3) RSRQ

Another quality indicator necessary to analyze is the RSRQ - Reference Signal Received Quality - since only a good RSRP value is not synonymous of good signal quality and, on the other hand, the RSRQ can be an indicator used to determine which is the best cell for the mobile device to connect and also for the handover process, since this process can be triggered by both the RSRP and the RSRQ value, by which determines the best LTE cell to transfer the current connection of the UE.

RSRQ is an indicator calculated through (24), using the RSRP, the number of resource blocks used (N_{RB}) and the RSSI – Received Signal Strength Indicator – (which represents the total value of the received signal strength, including non-serving neighbor cells, co-channel, adjacent cells and thermal noise), being always better the higher the RSRP value and presenting more mediocre values when the RSRP is lower.

$$RSQ = N_{RB} \frac{RSRP}{RSSI} \tag{24}$$

RSRQ values are defined between [-19,5;-3] dB, as described in Tabel 13, with intervals of 0.5 dB [25].

Radio Conditions	RSRQ (dB)
Excelent	>= -10
Good	-10 a -15
Fair	-15 a -20
Cell Edge	< -20

Tabel 13: RSRQ rating [23].

RSRQ is quite important since the user, when moving, influences the radio conditions, with the possibility of moving to areas where the RSRP values may even be better, but due to interference problems the RSRQ decreases, which may lead to an handover in order to ensure the continuity of a stable connection. However, if both values, RSRP and RSRQ, decrease at the same time, it is indicative of coverage problems. In this way, when analyzing the RSRQ values of a mobile network, it is possible to identify areas in which some kind of action is needed in order to improve both areas with low coverage or areas with high interference that degrade the quality of service provided to users, which can lead to dropped calls or low throughput issues.

Through Table 12, it's possbile to verify that to guarantee good quality values in the mobile network, it's necessary to ensure RSRQ values greater than -15 dB, since below this value there is a probability of connection problems and even an inter-RAT handover (switching the connection to other technologies such as GSM or UMTS). By analyzing Figure 20, it's possible to see that throughout study area there are always values greater than -15 dB, which guarantees good coverage and negligible interference values.

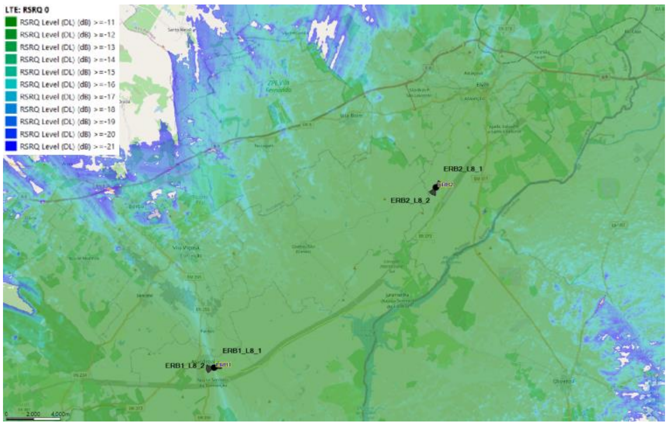

Figure 20: RSRQ obtained by simulation [24].

D. Cell Throughput

Finally, the maximum throughput values were simulated, in ideal radio situations and maximized LTE configurations, for the area under study, initially only for the highest priority band, L800, and then this one together with the L1800 band, as illustrated in Figure 21 and Figure 22, respectively.

Through the data obtained in simulation in Figure 21, it is possible to verify that for mobile devices served only by the L800 band or that only support one downlink CC, when in the service area of sector 2 of the RBS1, under ideally radio conditions, the maximum throughput that the mobile network can provide is values close to 90 Mbps.

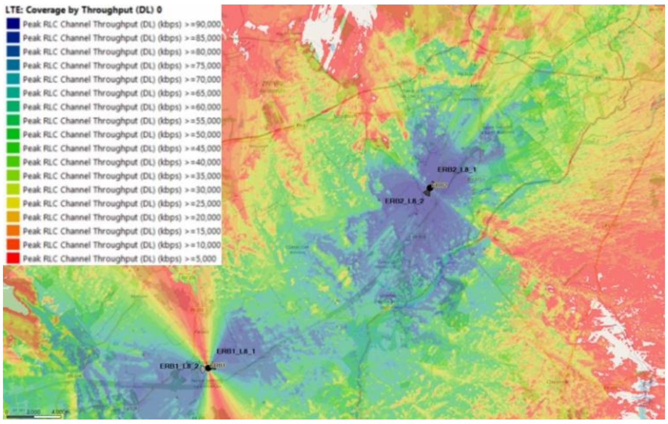

Figure 21: Throughput values for L800 obtained by simulation [24].

Posteriorly, simulating together L800 and L1800 bands, it is possible to verify through Figure 22, that under ideal radio propagation conditions, a mobile device that supports carrier aggregation and that is being served by sector 2 of the RBS1 can access to maximum throughput values close to 565 Mbps. Both throughput values, obtained in simulation, for one CC (L800) and for two CC's (L800 and L1800), are about 30 Mbps lower than the calculated theoretical values, described in Table 6. This fact is mainly due to the average speed factor of the mobile device, whose value directly influences the quality of the connection between transmitter and receiver, which in the simulation environment was configured as 120 km/h. However, this component for the theoretical formula of the bit rate, described in (1), is not taken into account.

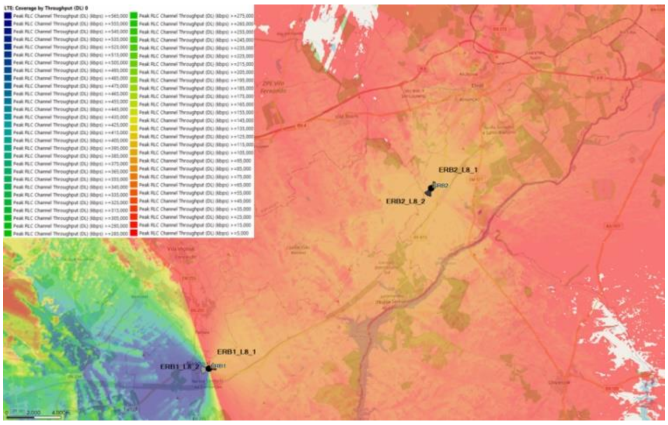

Figure 22: Throughput values for L800 and L1800, in CA, obtained by simulation [24].

V. CONCLUSIONS

The aim of this project is to approach the study and planning of an LTE network, as well as its parameters and performance. To accomplish this, were generated simulations of the planned network and later analyzed and compared with the theoretical values. For the study area, in Alentejo North, it was not only considered to ensure a good coverage, but also to guarantee the capacity of the mobile communications system to assure a good network performance to the users. For this purpose, several factors that directly influence the performance of the network were analyzed, such as coding schemes, modulation, propagation models, frequencies, type of MIMO or the characteristics of the equipment to be used.

The main indicators that influence the throughput values are the RSRP and RSRQ. In this project, its was ensured a RSRQ value, based on the results obtained, of at least -15 dB over the entire length of the study area, which guarantees a good mobile network performance, having in the cell border zones RSRP values between -100 dBm and -110 dBm. With these values it's unlikely to be able to maintain a data session with high bit rates, but in theory enough to be able to make voice calls.

The simulations obtained and analyzed in chapter IV were performed with the planning tool "Atoll", in rural areas, in the Portugal region of Alentejo North, between the towns of Alandroal and Elvas, with the installation of two radio base stations, both being planned with two sectors, using the LTE bands LTE 800 (four cells) and LTE 1800 (one cell), with bandwidths of 10 MHz and 20 MHz, respectively. For the maximum values of bit rate, under ideal conditions, were obtained 90 Mbps for the LTE 800 band and 565 Mbps with the carrier aggregation feature, using both LTE 800 and LTE 1800 bands, ensuring a very good performance of the mobile network. The bit rate values are very close to the theoretical values, both being smaller by about 30 Mbps, which can be explained by differences in calculation between the planning tool and the theoretical formula used, as is the case of the UE speed factor, taken into account during the simulations.

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