Radio Network Planning in swap 3G/LTE
Case study in Scandinavia

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Abstract— During the last years, the growth of data traffic, on mobile networks, has been huge and forecasts suggest a continuation of this growth. The adoption of LTE technology by operators is increasingly necessary and more frequent, thereby increasing the transitions between 2G/3G and LTE. This work was made in collaboration with Alcatel-Lucent and approaches this issue of change of technology by mobile operators. The aim of this project is analysing the several techniques and radio network planning processes, used in a process of transition between mobile technologies by an operator. Initially, we analyse the planning tools used by Alcatel-Lucent, presenting its main input data and their settings. For harmful situations to the network, such as, coverage gaps or overshooting, we used a set of radio optimization techniques, which reduce the impact of these problems. By the analysis to these techniques, we compared the cell impact of using mechanical tilt and electrical tilt, showing the benefits of both methods. To improve coverage, both possibilities are compared: optimization of equipment and the introduction of new sites. The results presented by the introduction of new sites are clearly higher than those obtained with optimization, in some cases, improving the coverage in 25%.

Index Terms—LTE; Radio Network Planning; Coverage; Optimization; Introduction of sites

I. INTRODUCTION

The technological development in recent years led to a growing need for improved information flows. In the mobile telecommunications area this fact was evident as there was a paradigm shift. The first generation mobile networks had as main services, voice and messaging, while in 3G and LTE, the data traffic has gained special importance. The growth of data traffic has been tremendous and is expected to continue to increase, getting the voice traffic with an insignificant expression compared to data traffic on mobile devices. According the analysis of Cisco, the monthly traffic in 2014 was 2.5 exabytes and it is expected to grow 10 times over the next 5 years, reaching 24.3 exabytes in 2019 [1][2].

This traffic growth happens due to the increasing use of internet on mobile devices (smartphones, tablets or computers). It should be noted that while smartphones are not currently the most widely used mobile device, representing only 29% of the equipments, the monthly traffic generated by smartphone in 2014 was 819 MB [2].

In order to support all this growth was necessary to develop new technologies. So, in 2008 the 3rd Generation Partnership Project (3GPP) releases the specifications for the Long Term Evolution (LTE).

In 2014, only about 40% of the population was covered by LTE, and it’s predicted that by 2020, at least 70% of the population were covered [1]. So, in coming years there must be a strong implementation of this technology in today's networks, becoming an important challenge for mobile operators. To accomplish this objective there are two possible scenarios: the introduction of a new and independent LTE network, or use the 2G/3G network as a basis for the creation of an LTE network. This second hypothesis implies a lower economic cost, but possesses several limitations from the previous network. The physical distribution, for example, is maintained between technologies, resulting in less flexibility in the distribution of sites and a consequent lesser capacity for physical optimization, after the introduction of LTE.

The development of this work was done in Alcatel-Lucent Portugal, which is a worldwide reference supplier on telecommunications area. One of its main area of action is providing LTE technology. This work falls within this context and is set in a real project for a client of Alcatel-Lucent in Northern Europe. This project is currently in progress, and aims to shift from 3G to LTE.

The transition between two different technologies creates numerous challenges to the client and to the supplier. Among the various processes executed, there is radio network planning, which plays an active role in the project, both at an early stage, with studies on the impact of new technology as well as a later stage of expansion and reinforcement of the mobile network. It is defined as objective of this work, analyzing the various techniques and methods used in the process of Radio Network Planning (RNP). It also aims to understand the possible solutions for the network in order to improve the quality of the radio signal, analyzing the advantages and disadvantages of each solution.

II. LTE FUNDAMENTALS

A. Initial requirements

The introduction of LTE aimed to the creation of the successor generation of 3G mobile networks, allowing follow the growth of networks, as mentioned in the previous chapter. Thus have been established a set of initial conditions that needed to comply with this new generation, some of which are the following [3]:

- The spectral efficiency for downlink (DL) should be 3/4 times higher than the previous generation, and uplink (UL) between 2 and 3 times;
- The frequency spectrum should cover from the 450 MHz to 2.6 GHz, and having a bandwidth in the range of 1.4, 3, 5, 10, 15 and 20 MHz;
- The peak throughput for the DL would be greater than 100 Mb/s and UL greater than 50 Mb/s, for a 20 MHz spectrum allocation;
B. Network architecture

The LTE network architecture is based on a network-oriented packet switching, so there is a paradigm shift from previous generations who worked in circuit switching. This new architecture, introduce some simplifications in the network, eliminating failure points and improving the efficiency by reducing latency. The compatibility with previous generation mobile is also maintained. As can be seen in Fig.1, this system consists of two major networks, notably UMTS Terrestrial Evolved Radio Access Network (E-UTRAN) and Evolved Packet Core (EPC).

![Figure 1 - Architecture of LTE Network [4].](image)

The E-UTRAN consists on intelligent base stations, called evolved Node B (eNB). The eNB are characterized by its autonomy and high performance, thus eliminating the need for a controlling entity of the various base stations as before. The ePC network consists of several components, with variables functions, including [3][4][5]:

1. **Mobility Management Entity (MME)** - is responsible for monitoring sessions, to send and request authentication User Equipment (UE) to Home Subscription Server (HSS). The MME is processing the signaling control plane between the UE and the ePC. Its functions can be grouped into two distinct categories: the functions related to the management of virtual logical connections (bearer) and functions related to the management of the link. In the bearer management is included the establishment, maintenance and release of bearers, running the session management layer on the NAS (Non-Access-Stratum) protocol. In the management of the connection, the functions included are the initial connection and security between the network and the UE, and is controlled by the connection management layer or mobility. Thus it is responsible for managing the handover and the roaming.

2. **Serving Gateway (SGW)** - do the routing of IP packets of users, while also acting as an anchor for the handover between different eNB. When the user is in the idle state, SGW retains information on the bearers and makes the temporary loading of DL information while the MME is not prepared to receive it. Additionally, it is responsible for the connection to other 3GPP data technologies (GPRS and HSPA) and performs administrative tasks on the accessed networks, such as data collection for the operator (for example traffic consumption).

3. **Policy and Charging Resource Function (PCRF)** - responsible for control policies and data flow by adjusting the bit rate according to the quality of service required. The PCRF provides QoS authorization, comprising a class identifier and data rate, ensuring that a given traffic flow is in accordance with the user profile.

4. **Packet Data Network Gateway (PGW)** – is responsible for the connectivity, linking users with the external data networks. PGW made the assigning of IP address to each UE and flow control, according to the rules established by the PCRF. This equipment makes the filtering of UE IP packets on the downlink (DL), based on the various QoS requirements for different bearers and performs QoS for a particular guaranteed bit rate (GBR). In addition, PGW serves as anchor point for networks that are not 3GPP (e.g CDMA and WiMAX).

5. **Home Subscription Server (HSS) -** corresponds to a database containing information about public networks. This data can be the QoS profile, or possible restrictions roaming networks to which a UE can connect. In this equipment, is also stored dynamic information, such as users which are registered in a particular MME. It can also be integrated the Authentication Center (AUC).

The connection between different eNB, also shown in Fig.1, is done via the X2 interface, to which the data plane traffic is called X2-U and the control plane is called X2-C. For the connection between the networks e-UTRAN and EPC is used S1 interface, which for the connection between eNB and the SGW is referred as S1-U. It is responsible for the user plane traffic, carrying for example, Internet traffic or voice over IP (VoIP), and thereby providing the connectivity to the remaining network users. For exclusive use of the control plane, and making the connection between the eNB and the MME, is used the interface referred as S1-MME, where all signalling is transported.

C. Multiple access techniques

The multiple access techniques used by LTE are Orthogonal Frequency Division Multiple Access (OFDMA) and Single Carrier Frequency Division Multiple Access (SC-FDMA). The OFDMA technique is used for the DL, allowing an improvement in spectral efficiency and is more robust in relation to interference. To UL is used SC-FDMA, which is a modified OFDMA technique, having a Peak Average Ratio (PAR) below when compared with OFDMA. So there is a reduction in consumption in devices, allowing for more efficient energy use [3].

The orthogonally of the OFDMA technique allows a more efficient use of spectrum, because it doesn’t require the use of a guard band, which in previous techniques was designed to prevent interference between sub channels. Thus, the removal of this guard band allows simultaneous delivery of a larger number of symbols, and a higher amount of data. For separating the DL and UL traffic, LTE supports both time division duplex (TDD) as Frequency Division Duplex (FDD). For TDD, the DL and UL connections use the same frequency but transmission is performed at different time intervals. Conversely, for FDD transmissions are performed simultaneously using different frequencies for the DL and UL.

The most adopted system is FDD because it is the market preference [3].
D. Modulation

Signal transmission is done via modulated signals as a baseband signal does not diffuse. The modulation consists in sending the signal to baseband by a carrier, which is modulated by the transmitter and demodulated by the receiver.

In LTE are used three kinds of QAM modulations (Quadrature Amplitude Modulations) according to the quality of the signal being transmitted, using carrier amplitude and a specific phase over finite periods of time. Thus, LTE supports QPSK (Quadrature Phase Shift Keying), 16-QAM and 64-QAM. For a lower quality radio, QPSK modulation is recommended as it is more robust. With the increased quality of radio signal, the 64-QAM becomes much more efficient that other modulations, being, however, less robust [3].

The 3GPP has defined a scale called Channel Quality Indication (CQI), with a growing range of values between 1 and 15. The scale is increased in accordance with the channel conditions, wherein the lower CQI values corresponding to the worst conditions and higher the better conditions. For situations where the signal strength is lower, QPSK modulation is used because this is most effective for such situations. Similarly, for a signal with good quality, i.e. higher CQI, the defined modulation is 64-QAM, which has a superior efficiency [3].

E. Type of transmission

In order to improve the results obtained in the transmission, LTE uses multiple antennas technique, being based on multipath that a signal may experience between a transmitter and a receiver. This method requires the use of several antennas in transmission and/or reception to thereby improve the signal quality, system capacity and coverage.

Applying this principle in both the sender and the receiver, allows obtaining Multiple Input Multiple Output (MIMO) technology, which is based on the use of two or more transmitters and two or more receivers. In this technique, and contrary to MISO, several transmissions are sent, and N transmissions require at least N antennas. For proper operation, it is necessary that the transmission of each antenna is uniquely identifiable by each receiver.

F. Quality of service and quality of experience

The bearer establishment allows the connection between two specific points on the network, where is establish a bearer between the UE and the PGW. Thus, according to the type of traffic that is intended, the network must guarantee a certain level of service for the logical connections. Through a set of QoS parameters of the network can ensure that service level.

The QoS parameters associated with a connection allow analysing the level of service offered through a range of indicators. This analysis will also vary according to the type of traffic of connection, wherein classes are defined for different traffic types. If these links have permanently housed resources are designated as Guaranteed Bit Rate (GBR), otherwise define them as non-GBR. Besides serving as characterizing the bearer, the GBR parameter also sets the debit amount guaranteed for this connection.

In recent years, a concept that has gained importance to operators is the quality of experience. Contrary to the QoS that is based on technical data, QoE is associated with how the user describes his satisfaction in relation to a service. This assessment can be done for instance on the form of use, speed, response time, and have as possible classifications, excellent, good, moderate, weak.

G. Propagation models

The propagation models are important because they give a prediction about the capabilities of mobile network or a specific connection by calculating the path loss. In this way it enables the assessment of cell coverage and is used for network planning. Its utilization allows optimizing the network, whether in terms of reducing interference, improving signal quality, or the placement and equipment configuration. The propagation models can be of different types, and may be designated as [6] [7]:

- Empirical, which are characterized by simple equations derived from intensive field measurements, in real environments. They have a great versatility as it can be applied to a wide variety of environments, but they must have similar characteristics to environments where measurements were performed. Examples of such models are the Okumura-Hata, COST 231-Hata and Standard Propagation Model (SPM).
- Deterministic, which are based on numerical approximations, and require a great level of detail of input parameters and a large computational complexity. The ray tracing method is an example of this model, which calculates several paths between the transmitter and receiver.
- Semi-empirical, which are obtained by combining the deterministic models and empirical, assuming some conditions as standard. The main model is the COST 231 Walfisch-Ikegami.

For this project, it was decided between the client and the ALU that the model used was the SPM, which will be detailed in the following chapters. The SPM model is based on the Okumura-Hata model and its extension, the COST 231-Hata model.

H. Electrical and mechanical tilt

The tilt, as name says, corresponds to the tilt given to an antenna in relation to its axis. Its value can be given in degrees or gain. There are two kinds of tilts, the electrical and mechanical, being necessary to distinguish its implementation and its impact on the coverage of a transmitter. Fig.2 presents these two kinds of tilts, identifying their axes and measurement angles.

The mechanical tilt corresponds to the physical change of the antenna axis, tilting it in the desired direction, and modifying the signal propagation directions. The electrical tilt does not imply changes to the physical antenna, but the change of the signal phase, thus changing the antenna radiation pattern.
In Fig.2 are shown the mechanical angle and the electrical angle. The results obtained with the single use of mechanical tilt, electrical tilt, or a combination of both methods, are always dependent on the environment in which the eNB are inserted [9]. In general, it is considered that the choice between the application of electrical or mechanical tilt have a negligible impact on coverage. The most important aspect is the overall value of tilt, given by the sum of both methods.

Regarding the maximum values of tilt that can be implemented in antenna, these are dependent of technical and environmental limitations. At the technical level, the limitations depend on the manufacturer and the model in question. In the case of mechanical tilt, the maximum value is imposed by the extender placed on the antenna socket holder, and by the first minimum angle of the antenna radiation pattern, which may not exceed the skyline. For electric tilt, the limit is imposed by phase shifting, that antenna allows to be inserted through the adjustment knob. Technical limitations may be aggravated by environmental conditions of the area where it operates the EB.

Sometimes, in the presence of a specific environments and especially rugged terrain, the impact of the application of these different methods, leads to different results. In these situations, the introduction of mechanical tilt keeps a greater width coverage, but causes an increase of rear lobes. Moreover, the use of electrical tilt, allows the signal to focus energy in the central area and also reduce the back lobe [8].

I. Neighbours plan

The list of neighbour relations of each cell is an important help in managing a mobile network. Through this list, a cell quickly knows the existing cells in its neighbourhood, facilitating mobility processes as handover.

In LTE this information is even more important, because due to the architecture of this network, the handovers occur mainly between eNB, without direct interference from a central controller or device. In this technology, this process is facilitated by the existence of the function Automatic Neighbour Relationship (ANR), which permits an automatic update of the neighbour list of each cell. This function is present in each eNB by making an active management of the neighbour list of that eNB.

The UE that is connected, and the neighbours eNB are the ANR main source of information. When requested by the eNB, the UEs may take measurements at the radio level in their neighborhood and report that information to the eNB. In addition, the neighbouring eNB also sends information regarding its own neighbourhood via the X2 protocol.

The ANR main functions involve the creation and addition of neighbour relations, by analysing the information of UE and eNB, managing these relationships, and removing those that are considered obsolete. Thus, for each cell there is a table managed by the ANR, containing the cells that according to certain parameters, are considered neighbour. The establishment of a neighbour relationship allows a cell to store various parameters and identifiers about their neighbouring cells, mainly the Physical Cell Identifier (PCI) that is the primary identifier of a cell and its distribution over the network must meet certain rules [3]:

To obtain a PCI, the below expression were used:

$$PCI = PSS + 3 \cdot SSS$$

PSS is the Primary Synchronization Signals with possible values of 0, 1 and 2. SSS is the Secondary Synchronization Signals, with values between 0 and 167. Thus, there are at most 504 possible values for PCI.

III. LTE RADIO NETWORK PLANNING

A. Introduction

The introduction of LTE in mobile networks around the globe is the natural response of operators to user needs. The introduction of this technology can be done in two ways: by introducing an environment where there is no mobile network, or may be made updating a network of 2G / 3G, using it as the basis for LTE, being called swap. This work follows an Alcatel-Lucent project, where it is proposed to carry out a swap of two mobile operators. These are located in three countries of Scandinavia, particularly Norway (Operator A), Sweden and Denmark (operator B). The goal of the project involves the upgrade of the current network in 3G (CDMA450) to an LTE network in the 450 MHz band (LTE 450) and additionally with the bands of 800 MHz (LTE 800) and 1800 MHz (LTE 1800). For the execution of swap with this size it is necessary and important to define steps and goals to be met over time. Thus is defined a generally three phases:

1) Preparation - is the initial phase of the project, which mainly are defined and validated all the procedures to be performed and the values to be achieved by Key Performance Indicators (KPI). It’s made an RNP analysis, allowing to make an initial evaluation of the overall network status.

2) Validation - where the first field tests are conducted. Initially are analyzed only four or five eNB, being applied to these, all the tests and validation procedures defined in the previous phase. Thereafter the process repeats itself, but for a cluster-test (approximately twenty eNB), in order to validate all procedures.

3) Implementation – it is the last and longest phase of the project. In this stage is done the swap across the network, which needs to fulfil all the procedures set in phase 1 and validated in 2. After the integration of eNB, an optimization of network is made accordingly to the results obtained and the requirements of customer.
The process of Radio Network Planning (RNP) is particularly important in the preparation phase, allows to get an overview of network status. The most relevant analysis is done through the use of special tools, which through a set of inputs (geographic data, equipment) allow to obtain an estimate of different network indicators. These results are presented either statistically or graphically, and make possible to identify various problems such as covered areas failures or high noise. In the simulation and prediction component, RNP also includes the planning level of the list of neighbouring cells and PCI.

In phases of validation and implementation, the RNP tasks include analysis of detected failures by the monitoring teams and consequent optimization of the existing network. For the resolution of faults, the usual solutions include the adjustment of the eNB under examination or the introduction of new sites.

B. Description of the tools

In a radio planning process, regardless of the technology used, the use of IT tools is increasingly indispensable. The use of these materials allows a faster and more efficient planning. In this section are described, the Link Budget tool, and the main simulation software used by the ALU, the 9955 RNP.

The link budget is a process which aims to evaluate in the project context, the expected value range from one cell to guarantee a certain service at the edge of the cell. The link budget is based on the calculation of the Maximum Allowable Path Loss (MAPL), between the equipment of the eNB and the user equipment. Thus, using propagation models, the range is evaluated from each cell to the various data services. Calculating the link budget in Alcatel-Lucent is done using an internal tool, suitable for the purpose. To obtain results with this tool various inputs are needed, including: density sites per area; requirements in terms of data transmission rate within the limits of the cell; frequency bands and bandwidths used in the LTE network to be implemented, which are the 450 MHz/5 MHz, 800 MHz/1800 MHz and 10 MHz/20 MHz.

The results of this tool can be displayed in various ways. May refer to which signal amount is required for a service to be available in the boundaries of the cell, and can present the range of the cell, in km. This information can also be used to evaluate if the number of sites is sufficient to meet the proposed objectives of coverage level for a given area. Some parameters follow recommendations of the 3GPP network, and in other cases, values are from ALU standards. The link budget is always calculated, as in previous technologies, taking into account the limiting scenario of UL. Factors contributing to this limitation may be the connection establishment procedures or data rates necessary for user services.

Table 1 presents the necessary levels, in each band, for reaching the various services within the limits of the cell, obtained through the link budget tool. The service, for example, PS 64, is a packet switch service at 64 kbps. Thus to obtain a service of 512 kbps using the band of 450 MHz, it is necessary to have a minimum value of RSRP -101.5 dBm.

<table>
<thead>
<tr>
<th>Service at cell edge</th>
<th>LTE 450 [dBm]</th>
<th>LTE 800 [dBm]</th>
<th>LTE 1800 [dBm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>PS 64</td>
<td>-108.2</td>
<td>-110.7</td>
<td>-115.2</td>
</tr>
<tr>
<td>PS 256</td>
<td>-103.89</td>
<td>-106.39</td>
<td>-110.94</td>
</tr>
<tr>
<td>PS 512</td>
<td>-101.50</td>
<td>-104.00</td>
<td>-108.56</td>
</tr>
</tbody>
</table>

The main planning software used by Alcatel-Lucent is a special tool, called RNP 9955. This program possesses a working environment that combines power with flexibility. It provides a nice way for the user, and an integrated set of tools that enables the creation and configuration of a radio planning project in a single application. The tool planning capabilities cover the different radio technologies in 2G, 3G and LTE [10]. The 9955 RNP software requires several input parameters, where we highlight the physical parameters of the network and the specific parameters of the used technology. The simulation options used most frequently are the coverage and noise predictions, generation of neighbour relations and PCI. The results usually allow a complete graphical analysis, exportation to other tools (Google Earth, TEMS) or a simple numerical and statistical analysis.

C. Inputs

This section describes the various inputs required to obtain results with the 9955 RNP tool. The main working bases are the geographical data, the placement and physical configuration of the base stations and the type of equipment used in the network.

In planning project, the geographic databases are essential, especially the terrain databases and environmental databases. In this report have been analyzed two different areas, zone 1 and zone 2, exemplifying the different kind of environments that have been encountered in the implementation of this project. Zone 1 corresponds to a predominantly urban environment near the ocean and with a moderately rugged in outdoor areas, with an area of 137 km². Zone 2 is a rural and an extremely rugged environment, with an area of 3382 km².

The Digital Terrain Model, contain essentially the height above sea level, for all positions of the geographical area in question. For this work are used databases with a resolution of 25 m.

The geographical distribution of different environments is given by clutter. In this work, this data contain 15 different types of environments. Each of these environments has associated a value of propagation and attenuation. With the introduction of this information, the performed simulations reach values closer to the existing values in the field. In addition, it allows identifying areas and points of interest, such as urban or industrial areas.

The antenna types and parameters is also an important input for planning tool. In analysed areas were used 10 different antenna models. They present gains ranging from 12 dBi and
18.34 dBi, horizontal openings between 62° and 68°, and vertical openings between 5° and 19°. The frequencies, as expected, are within the range of bands used in the project, i.e., 450 MHz, 800 MHz and 1800 MHz. The use of this wide antennas range is due to various reasons, technical and environmental, but mainly to the re-use of the existing network. The use of three different bands, associated with large design, and the fact that there are many different environments, with typical situations also require the use of special equipment. For example, for the 1800 MHz band used mainly to offload traffic, it is apparent that the antennas of these base stations have higher directivity than others. Also noteworthy is the decrease in the gain of the antennas when there is a decrease in the used band. The smaller antenna gains are for 450 MHz band, and higher values are for 1800 MHz band. These differences are due to the limitations of antenna design. The decrease in the antenna bandwidth implies an increase in wavelength, resulting in an increase of the antenna surface. Thus, to keep equipment at acceptable dimensions, the gain for the band of 450 MHz is less than the remaining bands.

In order that predictions made by the RNP 9955 became closer to reality, it is necessary that propagation models used are perfectly adapted to the environment under study. For this work it was used the ALU SPM model. This model were adapted to the three different used bands, and two different environments, namely dense urban/urban and suburban/rural.

As mentioned above, the project under consideration is large. The target country has a total of 552 sites and 1908 base stations, in the different used bands. Table 2 shows the number of devices for the areas analyzed in detail in this paper. As was expected, the BS in the band of 450 MHz are dominant, approximately 70% of the entire network. In the opposite direction, use the 1800 MHz band is at this stage, residual, and it is used only in large cities to perform traffic offload.

<table>
<thead>
<tr>
<th>Sites</th>
<th>Base stations (by band)</th>
<th>LTE 450</th>
<th>LTE 800</th>
<th>LTE 1800</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 1</td>
<td></td>
<td>29</td>
<td>40</td>
<td>76</td>
</tr>
<tr>
<td>Zone 2</td>
<td></td>
<td>13</td>
<td>26</td>
<td>18</td>
</tr>
<tr>
<td>Total of country A</td>
<td></td>
<td>552</td>
<td>1342</td>
<td>546</td>
</tr>
</tbody>
</table>

It is observed that the site density is clearly higher in zone 1, where there are many sites that have two or even three different bands. Thus, the region 1 is composed of 29 sites that support a total of 130 BS dispersed over an area of 137 km². Zone 2, which covers an area of 3382km², possesses only 13 sites, which have in total 44 BS. The introduction of sites, transmitters and cells in design tool occurs in a simple way, being possible to import data in Excel format.

D. Validation criteria of radio coverage

To validate the radio coverage of project, a set of indicators and levels that need to be achieved were defined:

- **RSRP - Reference Signal Received Power**: it is the main parameter in the coverage analysis. The levels were set in the Link Budget and are differentiated for the frequency band in use. This range ensures minimum values to achieve the various services (PS 64 to PS 1024) on the cell edge.
- **RSRQ - Reference Signal Received Quality**: this parameter is also associated to the coverage, being calculated from the division of RSRP by the total received power. For the validation of this indicator, it was determined that the RSRQ on the DL must have a value not less than -15.5 dB, for a 50% load cell.
- **RS SINR - Reference Signal, Signal to Interference plus Noise Ratio**: this indicator allows analyzing the signal quality, by the calculation of ratio between received power and the interference and noise. The validation level was defined that RS SINR must be greater than or equal to -2 dB, for a load cell at 50%.
- **Overlap 4 dB**: this prediction evaluates the receipt of an UE in the area under review. It is checked if in relation to the best cell server, other signals are received with a maximum difference of 4 dB. As requirement for this indicator, it was determined that the area percentage of 4 or more servers must be less than 2%, and the area with 2 or more servers must be less than 35%.

IV. ANALYSIS OF RESULTS AND RADIO OPTIMIZATION

A. Radio optimization techniques

In RNP process are used different techniques for analyze and optimize mobile networks. In the following subsections were listed different techniques and methods through information provided by the planning tool allow detection of faults and the improvement of network quality.

i) **Coverage verification**

To estimate coverage the RSRP indicator is analyzed, allowing to identify areas that have no coverage. This analysis is done by frequency band and uses the levels set out in the criteria for validation of radio coverage. The analysis is done graphically, by identifying lacking coverage areas. To this analysis, the RSRP predictions are superimposed with the DTM and an array of priority areas to ensure coverage, which usually are the residential areas.

ii) **Electrical and mechanical tilt adjustment**

The addition or removal of electric and/or mechanic tilt is one of the main methods of radio optimization, allowing to correct and improve the coverage of a mobile network. By adjusting these parameters, it is possible to direct energy to the areas of interest by offering better signal levels. The use of electrical or mechanical tilt, with too high or too low values, possess a similar behavior for both methods in terms of coverage.

To obtain the recommended tilt value to implement, trigonometric relations can be used to do calculations.
However, this method produces only an estimate of the values that can be used as tilt.

Due to different impact of electrical and mechanical tilt, in situations with a rugged terrain and a steep slope, the use of BS with an umbrella configuration allows an optimization of coverage. This type of configuration is based on the introduction of a negative value of mechanical tilt in conjunction with a positive value of electrical tilt. Table 3 shows a comparison between the typical configuration of mechanical tilt, electrical tilt, and the implementation of umbrella configuration.

Table 3 - Application results with different tilt configurations [11].

<table>
<thead>
<tr>
<th></th>
<th>a) Electrical Tilt = 0° Mechanical Tilt = 8°</th>
<th>b) Electrical Tilt = 8° Mechanical Tilt = 0°</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
</tbody>
</table>

The image a) corresponds to the exclusive application of mechanical tilt, verifying a dispersion of power by the side areas, and the existence of a considerable rear lobe. The image b) shows the application of only electric tilt, observing a higher concentration of power in the central area, as well as the reduction of the lobes on the opposite direction of spread. The configuration of the umbrella type, which is in the picture c) demonstrates how there is a huge reduction of radiation in the opposite direction to the spread (rear lobe). So it allows a reduction of interference by the BS and a more exact definition of what is the best server cell.

iii) Verification of overshooting

The overshooting phenomenon occurs very often in mobile networks and can drastically reduce the quality of a network, in particular the area where it occurs. The overshooting is the existence of several zones in which a cell is dominant (best server), but that is outside the normal coverage area. It is mainly caused by antennas located at higher and lower areas, but also due to reflections in the environment. This phenomenon causes a huge degradation in signal quality as well an increased interference to neighboring cells that also increases handovers.

In this project to verify the occurrence of this phenomenon the best server prediction is used. This prediction enables to analyze the transmitter coverage and to detect various situations that are bad to the quality of the network as the overshooting, the existence of dominant neighboring cells or excess of downtilt.

iv) Changing the frequency band

The use of three different frequency bands allows to change the frequency band in use that is an appropriate solution to solve coverage and/or interference problems. If a cell is always dominant in the surrounding area, the cells totally covered by this higher cell should change to a different band. For the 1800 MHz band, that is normally used to make traffic offload, their use in residential areas where the coverage range can be less, is a viable solution.

B. Analysis of results

To analyze the predictions obtained using the planning tool, and in order to validate coverage, the results must be in agreement with values presented in section III-D. The review will be done in stages, initially being only RSRP, then the best server and finally the other indicators. Optimization techniques shown in previous section were applied, in order to correct the detected problems. Analyses were subject, to zones 1 and 2, presented in section III-C.

i) Coverage analysis – RSRP

The RSRP prediction for zone 1 in LTE band 450 is shown in Fig.3. For areas of interest (shaded light) were detected three areas with coverage gaps, marked with yellow circles. The coverage area is statistically shown in table 4. It is noted that overall statistical results are good and there is coverage to PS 512 service in 99.2% of the area, which corresponds to 135.16 km².

The same predictions were done for LTE 800. It is noted that coverage in this band is generally good, with PS 512 service being hit in 93.5% of the total area. The LTE 1800 being used only in some cells, didn’t provide reliable statistical information. To this band, is recommended to analyze only the zones with BS in LTE 1800. The analysis is also repeated for the zone 2.

![Image](image3.png)

Figure 3 - RSRP prediction for LTE 450 in zone 1 [11]
Table 4 - Results of RSRP prediction for LTE 450 [11]

<table>
<thead>
<tr>
<th>RSRP Outdoor - LTE 450</th>
<th>Surface (km²)</th>
<th>Area (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PS1024</td>
<td>134.2981</td>
<td>98</td>
</tr>
<tr>
<td>PS0512</td>
<td>135.8931</td>
<td>99.2</td>
</tr>
<tr>
<td>PS0256</td>
<td>136.4969</td>
<td>99.6</td>
</tr>
<tr>
<td>PS0064</td>
<td>136.9019</td>
<td>99.9</td>
</tr>
</tbody>
</table>

ii) Best server analysis
The best server prediction of LTE 450 for zone 1 are shown in Fig.4. There are identified and numbered various situations of overshooting.

After analyzing the different areas indicated, the following situations were identified:

1. Overshooting due to the use of very low tilt values in cells that were to cover these spaces - areas 2 and 4;
2. Overshooting caused by the fact that cells use high values of tilt and / or are located in high points of land - area 3;
3. Overshoot caused by both the lack of coverage as well as the existence of the middle characteristics favorable to the onset of this phenomenon, for example, river, mountains or valleys - areas 1 and 5;

Only zones framed in situations 1 and 2 are considered to be priorities, requiring thus proceed to its correction and optimization. With the application of various techniques presented in section IV-A, in particular the tilt adjustment and overshooting check, it was possible to correct the detected problems. The only parameters that have been subject to evaluation and change were the tilts. When possible, they chose preferably by electric tilt modification, since it implies lower costs for the customer. It was possible to fix problems identified with the numbers 2 and 4.

The remaining bands (LTE 800 and 1800), and the zone 2, were analysed using the same procedure.

iii) Analysis of remaining indicators
After the analysis of RSRP and best server, the results of the remaining KPI set out in section III-D, were checked, confirming that they meet the established levels to ensure the signal quality. Note that these simulations refer to the state of the network without introducing modifications. It is presented in table 5 the results for this set of KPI for the zone 1, in LTE 450 band.

Table 5 - Remaining KPI results in LTE 450 and 800, for zone 1 [11].

<table>
<thead>
<tr>
<th>Name</th>
<th>Objective</th>
<th>Percentage of area</th>
<th>Zone 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>RSRQ</td>
<td>100% with RSRQ &gt;= -15.5</td>
<td>98.1</td>
<td>88.6</td>
</tr>
<tr>
<td>SINR</td>
<td>100% with SINR &gt;= -2</td>
<td>96.4</td>
<td>83.8</td>
</tr>
<tr>
<td>Overlapping 4dB (%)</td>
<td>Area with 4 servers &lt; 2%</td>
<td>4.6</td>
<td>11.7</td>
</tr>
<tr>
<td></td>
<td>Area with 2 servers &lt; 35%</td>
<td>35.7</td>
<td>44.2</td>
</tr>
</tbody>
</table>

In zone 1, for LTE 450, the levels of RSRQ and SINR for the established criteria have values of 98.1% and 96.4%. The area under study possesses a diverse environment, having in its constitution 10% of ocean and 22.4% of forest. Since these areas with few exceptions, are areas uninteresting to coverage, the RSRQ and SINR indicators can be validated for this band and zone.

Regarding overlapping indicators for the zone 1, it is seen that values are above the level of validation. As mentioned above, the diverse environment of the area under study, implies a decrease in the quality of results. In forest zone the cell density is lower, and the environmental conditions impose greater attenuation. Thus the signal quality decreases and there is no clear definition of dominant cells. This combination of factors results in an increase of the overlapping, since there are now a set of cells providing similar signal levels in that area. Thus, although statistically didn’t being achieved the values specified in section 3.4, and considering the reasons given, it is possible to validate this two KPI.

Consequently, with all KPI validation, it is possible to confirm the coverage validation for zone 1. It is only necessary that these indicators are met in one of the bands that provide coverage for the area under study. However, to confirm the band of the LTE coverage quality 800, an analysis is made of the same indicators in this band. With information of table 5, it is possible to conclude that globally the results from LTE 800 band are worse than LTE 450.

C. PCI plan
The PCI plan should be prepared accurately because of its importance to the correct operation of LTE network. It is necessary that distribution were made taking into account all project network and possible neighboring networks. A PCI is calculated from equation 1, using the PSS and SSS. As mentioned in section II-I, the PCI that can be used in a mobile network, are limited to the range from 0 to 503. This project include two networks of different operators in three different countries, demand the restriction of the use of PCI, being
necessary a division of the total PCI, by each country and borders.

To generate PCI plan, a feature included in 9955 planning tool were used. Due to various restrictions and the different areas of allocation, the tool was used separately for each region. In relation to the reuse distance, initially was used the amount of 200 km. In order to optimize the allocation of PCI, the reuse distance was reduced gradually, trying to achieve a situation without collisions, and with the smallest reuse distance. After this iterative process, it was possible to make a PCI allocation without collision for all areas, with the use of a reuse distance of 160 km.

D. Neighbours plan

The neighbours plan is an important support to mobility operations such as handover. In this project, the development of an initial neighborhood plan was required. Later the network will manage this information through the ANR. It was used as a base, the network neighbors list of the previous generation. With the help of the 9955 program, this list was analyzed, checking if the following rules were met:

- Each cell may have a maximum value of 32 neighbor relations per band and all cells belonging to the same eNB, even in different bands, should be considered as neighbors;
- The cells that are within a 10 km radius should be included in the list;
- There are no cells with empty lists, and all connections must be established symmetrical, i.e. if the cell A is a neighbor of B, B is also a neighbor of A.

The use of planning tools for the analysis and verification of previously presented rules is essential. The complete neighbor list for the entire network, with about 1900 cells, easily reaches 32000 neighborhood relations.

E. Study case: optimization versus introduction of new sites

After the swap, with the integration of new base stations, it is required to do tests on the ground. The following study case arises during this phase. A test fixed-point, similar to a typical user was installed in a zone which is intended to offer mobile coverage identified in the figure as IMSI. The area of interest is the lake border where was installed the test device. This device was doing many handovers daily, reaching values around 200 handovers per day. Considering that in a fixed point, the occurrence of handovers should happen very occasionally, these reported values indicate some problem.

So it was requested, to make a RNP study, checking the current status, identifying the reasons for the failure and suggesting possible solutions.

To analyze the initial state of the network an analysis of RSRP, SINR and best server predictions were performed. These predictions were calculated considering the existence of indoor losses clutter. The aim is recreate an environment closer to the real situation, where the test equipment was placed in indoor environment.

Fig.5 shows the prediction of RSRP, being visible that in IMSI vicinity the coverage had an overall maximum level of -110 dBm. In addition to this low value of RSRP, the best server analysis shows that there is no cell that is fully dominant in the area of interest. This alternation between dominant and blurring cells causes an increase of handovers and consequently a reduction in QoS.

The ability of surrounding cells to offer coverage was analyzed, concluding that every cell have some obstacle, reducing the coverage to IMSI zone. To correct these problems, there are essentially two possible approaches. Make up an optimization in existing sites by adjusting the physical parameters such as the height of the masts, the azimuth and tilt. Another possible approach involves the introduction of new sites in areas of interest.

In the first approach, some changes were applied to the 3 cells with capacity to offer signal coverage in IMSI zone. These changes have gone through the application of certain techniques listed in section IV-A, as the setting of the mechanical tilt, and by changing the azimuth and the heights of the masts. The most significant changes happens in one cell because it is the nearest and possesses less obstruction in line of sign. The solution passes by an increase of antenna mast to 35 m, an adjustment in azimuth of 40°, and an increase of mechanical tilt, partly due to the increased height of the mast.

As already mentioned, the alternative solution to optimize, is the introduction of new sites. For the area under study, given its form and dimensions, it is concluded that was necessary to introduce only one site with two BS. It was determined that the location of this new equipment should be on the opposite of IMSI, in a relatively high point. The location of new equipment is always dependent on the analysis made on the ground, studying the feasibility of implementation.

To determine which of the options induces in the network a more significant improvement, the RSRP values of each solution have been compared to the initial values, presented in table 6. It is observed that by optimizing, only a small improvement had been achieved. In the highest RSRP level, the improvement was approximately 6.9% in total covered area. The introduction of a new site, allows an improvement of 24.1% at this level, and 19.8% at -102 dBm. In Fig.6 is represented the RSRP prediction after the introduction of new site.
In table 7 are presented the SINR results before and after optimizations. There is a significant improvement in SINR with the introduction of a new site, with SINR level greater than 8 dB passing from 19.8% to 56.6%. It is also noted that there is a doubling of the percentage of area with SINR higher to 12 dB, and for almost the entire study area (99.3%), the SINR level is greater than 0 dB.

With these results it is possible to conclude that solution with the higher improvements is the introduction of a new site. It gives a great QoS improvement and the coverage of this new site will be confined, reducing interference. This solution has a higher costs and a slower implementation when compared with optimization of existent sites.

Table 7 - Comparison of SINR results of study case [11].

<table>
<thead>
<tr>
<th>SINR Prediction (dB)</th>
<th>Percentage of area (%)</th>
<th>Initial state</th>
<th>After optimization</th>
<th>After introduction of new site</th>
</tr>
</thead>
<tbody>
<tr>
<td>SINR &gt;= 12</td>
<td></td>
<td>14.8</td>
<td>19.5</td>
<td>19.9</td>
</tr>
<tr>
<td>SINR &gt;= 8</td>
<td></td>
<td>32.1</td>
<td>37.1</td>
<td>47.4</td>
</tr>
<tr>
<td>SINR &gt;= 4</td>
<td></td>
<td>71.8</td>
<td>67.9</td>
<td>80.6</td>
</tr>
<tr>
<td>SINR &gt;= 0</td>
<td></td>
<td>100</td>
<td>100</td>
<td>99.6</td>
</tr>
</tbody>
</table>

V. CONCLUSION

The main objectives of this work were the analysis, understand and improvement of radio planning techniques for LTE technology that were fully achieved. Another goal was to obtain technical expertise on the LTE, especially on the radio planning that were realized.

The initial procedures passed by the acquisition and introduction of various databases in 9955 RNP tool. An analysis to coverage in the three countries was made to the project application area, identifying possible problems. With the development of the project, analyzes were requested to areas in particular, where through optimization techniques presented, the various solutions were compared.

Due the increasing use of mobile data by users, more LTE networks will be implemented by operators, and the swap projects will be more frequent in future. So, the process and techniques applied in this work will be more important for network suppliers.

About studied optimization techniques, the implementation of electrical tilt, mechanical tilt or Umbrella configuration must be studied deeper, because as shown in this work, a correct application of this techniques allow an improvement in coverage.

Comparing the two possible methods for solve coverage problems, the best solution is the implementation of new sites instead of optimize the existent cells. This first solution allows a great QoS improvement but have a higher cost and a slower implementation. The physical optimization of existent antennas, sometimes maybe not be applied (e.g. increase antenna height sometimes is not possible). Other problem of optimization, is that in some cases, this changes didn’t have the same results those calculated by planning tools.

REFERENCES