LTE Mobile Network performance with Antenna Tilt considering Real Radiation Patterns

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Abstract

Due to the increasing demand of traffic, mobile networks require flexibility to modify the area of service at any time. The use of antenna tilt is a crucial element in the design of modern networks as this element can modify the area of served cell and affects several parameters like coverage capacity or energy. The tilt of antennas automatically with remote electrical tilt (RET) is particularly relevant due to new smart networks that require the control of the system remotely. However, RET has limitations as a result of the imperfections of the design of real antennas. This is due to the fact that the whole pattern can vary for each tilt iteration.

This study proposes a system level simulation of two real antennas with similar characteristics like gain, beam width and frequency, in order to evaluate the results in terms of coverage and capacity for different degrees of tilt. The results show that remote electrical tilt improves both coverage and capacity up to 32% and 50% respectively. However the performance of both the antennas differ. For example, different sizes of networks are simulated and different degree of optimum tilt is obtained for each antenna, which is explained by the comparison of the radiation patterns. The difference between the angles of the optimum tilt for different sizes of the network also affects to the energy efficiency metrics that have been simulated. One type of antenna shows better effects when tilt is applied and the energy efficiency improves up to 13% with respect to the other antenna.

Through the comparison of the radiation pattern, it is possible to conclude which elements are the most important for different areas of coverage of the network. The high gain and the roll off of the main beam play an important role for cell edge coverage. In addition, sharp roll-off inclination and higher gain are the elements which have the strongest influence on tilt. Finally, the effect of side lobe levels on other parameters of the network is shown in this study. Lower side lobe level affects the areas closer to the base station and upper side lobe level interfere the adjacent cell. This study shows how these levels change for each tilt iteration and, thus, explains the difference in the performance of both antennas.
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List of Abbreviations

3GPP  Third Generation Partnership Project
AISG  Antenna Interface Standard Group
CCU   Central Control Unit
CDF   Cumulative Distributive Function
ECR   Energy Consumption Ratio
ERG   Energy Reduction Gain
GoS   Grade of Service
HPBW  Half Power Beam Width
HSPA  High Speed Packet Access
ISD   Inter-site Distance
LTE   Long Term Evolution
PCA   Portable Control Adapter
RAN   Radio Access Network
RCU   Remote Control Unit
RET   Remote Electrical Tilt
ROI   Region of Interest
SON   Self Organizing Networks
SINR  Signal to Interference plus Noise Ratio
SIR   Signal to Interference Ratio
TTI   Transmission Time Interval
UMTS  Universal Mobile Telecommunication System
WCDMA Wideband Code Division Multiple Access
1. INTRODUCTION

This introductory chapter describes the background of the topic and the motivations of working on the issue first, then the description of the found problem in combination with the research question is described; following that the scope of the thesis and, finally some important work related to the main topic is explained.

1.1 Background and motivation

The design of antennas for base stations is a concern for the deployment process since this element affects several aspects of the whole network as it is responsible for transforming the energy from the circuits in the base station into radiation energy [1] which makes the simulation with different types of antennas very important in order to obtain system-level performance. The tilt of the antenna is particularly relevant, which is the process of changing the direction of the radiated electromagnetic energy in order to improve the needs of the network for a particular moment.

The increasing demand of traffic and the huge quantity of users whom current networks have to provide services make the flexibility of the operation crucial. Antenna tilt is one of the existing solutions for these requirements, since it can improve and modify the coverage and capacity of the networks depending on the movements of the population and the required direction for the best radio communication link. Hence, the evaluation of this parameter is basic to improve the performance of the whole network.

Changes in the radiation pattern of the antenna, in terms of tilting can be produced by two mechanisms, electrical and mechanical tilt [2]. The most common type of tilt is the down tilt of the main directional point of energy in the vertical plane, i.e. the plane perpendicular to the ground. On the one hand, mechanical tilt adjusts the direction of the main lobe by physically moving the axis of the antenna so that this degree of tilt has no limitation and it is a flexible system to tilt the antenna towards one determined direction. On the other hand, remote electrical tilt (RET) remotely changes the shape of the pattern without physically moving the antenna through a system of phase change in the feeding of the antenna. The next figures that are presented in [2] will represent visually these systems:

![Figure 1.1: Representation of mechanical (left) and electrical (right) tilt [2].](image-url)
However, when tilt is applied to the antenna, not only does the main lobe of the vertical plane change, as it is described in [3], but the entire radiated pattern changes, i.e. besides the vertical plane, the horizontal plane can also distort when tilting. In the following figure, the distortion in the horizontal plane with different angles of tilt is described:

![Figure 1.2: Modification of the horizontal pattern with two mechanism of tilt [4].](image)

Moreover, the modification of the vertical plane is not only for the main lobe but also the rest of the pattern has distortions, which give directional antennas different effects depending on the transformation of the radiation pattern. Thus, it is very important to consider these modifications and when simulating different scenarios, the more realistic the patterns are, the more precise the results will be.

The effect of antenna tilt on mobile networks has been studied in different aspects as the related work will describe after. For instance, electrical tilt can be a significant factor for the shape of the vertical sectorization within an LTE network in terms of capacity gain as it is introduced in [5]. Furthermore, there are studies about the creation of pattern models besides the ideal 3GPP model so that there is an approximation of the radiation model to the real radiation pattern. This has been observed in [6], where the analysis of the proposed model in terms of capacity and spectral efficiency is evaluated, having a pattern more realistic than the ideal 3GPP model and trying to emulate a real antenna pattern.

However, it is observed that changes of tilt not only affects the coverage and capacity analysis, but it is also an important factor on LTE energy savings as has been described in [7]. As it will be explained, in many cases the simulations take into account approximations to represent the two planes of the antenna radiation pattern and it does not take into consideration the possible changes of a measured pattern. Thus, with all exposed above, antenna tilting has a big influence in different parameters of the network and it is an important factor to address while designing a network.

This document will focus on the impact of RET on LTE networks because this system is the most relevant when the new smart networks are coming nowadays. In fact, the introduction of the antenna tilt in the Self Organizing Network (SON) concept by the
3GPP Release [8] means that this system is one of the key points to control the operation of the optimization of the network by the vendors and operators. This introduction of the RET as a use case to improve the performance is an indicator to have standards that connect the RET with the rest of the network so that the operations are as efficient as possible and the new technology is adapted to the new needs. This previous fact and the impact of the electrical tilt on coverage and capacity for the optimization of the networks is the reason why 3GPP has standardised the control of RET by the network automatically by [9] [10]. Thus, the tendency of the use of RET for new self-organizing networks is the other big motivation to evaluate and study this system in detail, as this document does.

1.2 Problem description and research questions

So far, antenna tilt and the possibilities of this mechanism to affect the performance of the networks have been described. Thus, the simulation of system-level performance is especially relevant since results are useful for both antenna manufactures and operators to evaluate the behaviour of different antennas.

Many of the ideal antenna models are accurate approximations like the proposed model in 3GPP [11], which is used in the previous study [12] to find the optimum tilt by observing system-level measurements, as well as there are proposed models that have been compared to real models and it shows precise similarities as it is described in [5]. However, these models do not take into consideration the possible variation of the radiation pattern when tilting that the research in [3] shows.

The problem appears because the simulation of different antennas with real changes on the radiation pattern has not been achieved yet for the previous studies. Hence, the comparison of system-level performance results for different real radiation pattern on both vertical and horizontal plane is needed.

Thus, in general terms, the aim of this thesis is to complete a system level simulation on LTE network with different real antenna patterns with the aim to tackle the previous problem. In short, the aim is to state what the improvements of tilting for different real antennas pattern are and how the changes of the radiation pattern affect the different parts of a cell.

Particularly, in order to address the problem, the aim of this thesis will be summarized in answering the stated questions. The intention is to evaluate the capacity and coverage measurements of remote electrical tilt. Following that, a brief study of the energy efficiency when tilted the optimum degree is achieved and, lastly, observe the radiation pattern of the considered antennas and explain how changes affect the previous results. Thus, the goal of this statements is converted into answering the following research questions:
- What is the improvement of tilt optimization and which is the optimum angle by considering the effect on coverage and capacity in a macro cellular network and two different real antenna radiation pattern within various inter-site distance (ISD)?
- What are the energy efficiency values when the optimum tilt is applied for both antennas?
- When tilting the antenna, how do changes in the radiation patterns affect the received signal in each of the antennas evaluated?

### 1.3 Scope of the thesis

This thesis is aimed at finding the optimum tilt, its improvement in coverage and capacity and the energy efficiency study on the LTE network for two different real antennas. Furthermore, the pattern of both antennas will be compared to explain how the tilt variations affect to both radiation planes and, thus, to the network performance. In order to achieve this goal, in the next chapter the process of remote electrical tilt is explained for real antennas to study the functionalities of this mechanism.

Afterword, the methodology and the simulator in MATLAB that will be used are introduced in the following chapter, i.e. the 3D antenna model that this simulator uses and how the measurements of capacity, coverage and energy efficiency have been considered. Following that, a brief study of a comparison between the 3GPP ideal antenna and two real antennas is presented in order to assess the difference when using real antennas instead of an ideal one. Lastly, results of the simulations and the solutions to the research problems are presented as well as the comparison between the radiation patterns. Finally, the discussion, the closing summaries and the future possible work will conclude this thesis.

### 1.4 Related work

It is presented hereby some of the most comprehensive work that is related to the concerned topic and will be divided in three main blocks: first, the effect of antenna tilt on cases such as load balancing and SON is presented; secondly, the next section will focus on some real simulations and approximations of antenna radiation patterns and their global performance and, lastly the last part will introduce some studies about the effect of antenna tilt on energy savings and efficiency.

The master thesis in [4] provides a general understanding of SON at the beginning and its goal is to define some antenna tilting and assess the performance within load
balancing uses case, it also presents theoretically how the tilt affects the general radiation pattern in both vertical and horizontal plane. It is noticeable how the radiation pattern is simplified to obtain the results corresponding to link level simulation on load balancing:

![Figure 1.3: modelling of antenna pattern](image)

From this thesis two papers have been published, [13] where it has presented results in both link and system level load balancing. In spite of choosing a simple radiation pattern in the link level, very helpful graphics were developed to understand how tilting antenna alters cell load, received signal or SIR; on the other hand, in system level simulation it is chosen WCDMA with HSPA network model and several parameters are presented like throughput, GoS or the load in cells.

Secondly, the next group of documents has been chosen in order to have a review about simulations that use approximations of radiation patterns. In the next studies [12] [6] define the simple antenna horizontal and vertical planes and the 3D pattern by adding these two ones mentioned in the 3GPP releases. On the one hand, in [12] it chooses the main parameters from a real antenna (SLL, HPBW...) to represent both the horizontal and vertical plane as the azimuth and elevation gain.

\[
G_{az}(\phi) = \max \left( -12 \left( \frac{\phi}{HPBW_{az}} \right)^2, SLL_{az} \right)
\]

\[
G_{el}(\alpha) = \max \left( -12 \left( \frac{\alpha + \alpha_c}{HPBW_{el}} \right)^2, SLL_{el} \right)
\]

The evaluation of the LTE downlink channel is obtained with the antenna model presented. Particularly, the coverage and capacity measurements are the main study. In this work this previous research will be extended with a different antenna model, by using real horizontal and vertical antenna pattern instead as well as RET will be evaluated. On
the other hand, in [6] the simplest horizontal model is compared with the proposed model, generating the patterns to compare them in the simulations:

![Graph 1](image1.png)

**Figure 1.4: Comparison of antenna patterns [6]**

The proposed model is found to be more accurate and 3GPP model under-estimated cell isolation by providing macro-cell simulation case on HSPA and LTE and verifying that by using the simplest model of 3GPP the simulation is far from reality. In this work the horizontal 3GPP radiation pattern will be compared with two real antenna patterns and the difference among them will be presented and evaluated.

The next document where a 3D real antenna is also evaluated is in [14]. In this paper one single site with three sector is evaluated with a combination of electrical and mechanical tilt and its effect on Signal to Interference Ratio in a UMTS network. The results show an improvement when this tilting is applied for a single base station scenario and different degrees of tilt are needed depending on the cell size and the traffic load. The extension of this works takes in place in the evaluation of LTE networks as well as macro cellular scenario with 7 sites creating interference to the centre cell.

Finally, two documents are presented where energy savings as well as spectral and energy efficiency are examined. In [15] it is assessed the tilting of antenna beam related to the cell size, whose configurations are presented in order to reduce the transmission power consumption and the energy savings. The simulation is deployed in a HSDPA scenario with a simple antenna configuration as well as the relevant parameters to take into account are energy consumption ratio (ECR) and energy reduction gain (ERG), and, in the conclusion, a point is made about continuing with the research in energy topic within a
more complicated structure in LTE RANs. This work will be extended by adding a simulation of energy efficiency results for the optimum tilt of two different antennas. On the other hand, with a more complex scenario, in [16] the possibility of introducing a self-learning algorithm is investigated in a sense that the tilting optimization is chosen depending on the traffic conditions that take place in every current moment. Taking the model of the 3GPP antenna, these simulations achieve a very realistic scenario of a heterogeneous LTE network with results in both spectral and energy efficiency. A different model of the energy efficiency calculation is taken into account in this thesis in order to see the energy metrics when the optimum remote electrical tilt is applied for different antennas.
2. REMOTE ELECTRICAL TILT

Since remote electrical tilt is the mechanism used in the antennas that will be simulated, this chapter focuses on some important points about RET so that the process is clearer to understand by giving a detailed explanation hereby. First of all, the theory basis about phased arrays, i.e. the principle of modifying the shape of the radiation pattern of the antenna by changing the phase of the feeding signal, is introduced; secondly some practical methods to shift the phase of the signal within the antenna are explained in order to extend the theoretical description; finally, the element that controls the phase shifter, i.e. Remote Control Unit (RCU) will be presented briefly in order to understand the whole mechanism as well as the connection of this element with the eNodeB.

2.1 Phased Arrays

Mobile communication antennas are usually designed with a linear array of radiation elements, typically dipoles of a determined length depending on the specifications. The reason why these arrays are used is the flexibility of the design to implement a determined shape of the radiation pattern. The basis of the theory is explained in [17] where the next figure is presented to explain a linear array antenna with equidistant elements:

![Figure 2.1: Array with K equidistant elements [17]](image)

The radiation pattern of the entire array is obtained by the so-called operation pattern multiplication, i.e. the multiplication of the radiation function of one single element by the function called array factor [17]:

\[ S(\theta) = S_e(\theta) \times S_a(\theta), \] (2.1)

where \( S_e(\theta) \) is the radiation pattern of one element and \( S_a(\theta) \) is defined as follows:

\[ S_a(\theta) = \sum_{k=1}^{K} e^{jk_0(K-k)d \sin(\theta)}, \] (2.2)
Where $K$ is the number of elements of the array, $d$ is the distance between each other and $k_0$ is $k_0 = \frac{2\pi}{\lambda_0}$.

Therefore, this is a brief summary of the theory of a linear array with elements to the same distance and no phase difference to introduce the fundamentals. However, RET is produced when the main beam is steering due to the change of the phased signal in each element. This is again explained in [17], where the same visual description is found and the relationship between the array factor and the phase signal with which every element is fed:

\[
S(\theta) = S_1(\theta) = S_e(\theta) \sum_{i=1}^{K} a_i e^{j[k_0(K-i)d\sin(\theta_0)+\psi_i]}
\]  

(2.3)

The radiation pattern is the same as the previous formula but with an extra element of phase $\psi$. Assuming that the amplitude is uniform and the linear phased taper considered by [17] takes the form of

\[
\psi_i = -k_0(K - i)d\sin(\theta_0),
\]  

(2.4)
Then, the array factor in this case is [17]:

\[
S_a(\theta) = \sum_{i=1}^{K} e^{jk_0(K-i)d[\sin(\theta) - \sin(\theta_0)]},
\]

In this formula the variable \( \theta_0 \) makes the array factor the greatest value when \( \theta = \theta_0 \) because with this assumption \( \sin(\theta) - \sin(\theta_0) = 0 \). Therefore, by setting the phasing of the linear array with the linear phase as \( \psi_i = -k_0(K-i)dsin(\theta_0) \), the main beam will be pointed to the desired direction \( \theta_0 \).

So far the theoretical fundamentals of using a phased array to modify the direction of the main beam of the antennas have been presented. However, this theoretical model is not always implemented due to the restrictions of the design of the antennas on mobile base stations, where not all the elements are individually separated by having its own feed network. This is reasonable because of the limitation of the cable, wires, microstrip or any other technology that may be used for the feeding of the elements for a real antenna. For instance, in [18] the author emphasises the beam tilting in mobile networks and its aim to reduce interference and improve the coverage and shows a figure where a real base station with a designed antenna is presented with the tilting system:

![Remote Electrical Tilt within a base station antenna with 7 elements](image)

Figure 2.3: Remote Electrical Tilt within a base station antenna with 7 elements [18]

In this figure the mentioned design with groups of element with the same feeding branch takes place so that every group of element has a different phase for a determined moment. The capacity to achieve remote electrical tilt is dependent on the efficiency of the phase shifter and how fast this element can be controlled. The module that controls such a phase
shifter is the remote electrical tilt Unit, which is joined the network and it has its own software and way to operate. Thus, in the following section some phase shifter technologies will be explained and the last sub section ends with an explanation about the role of RET in a mobile network.

### 2.2 Phase Shifter Technologies

This chapter introduces briefly two types of technology that is applied to phase shifter within modern antennas: the shift can be produced by introducing an element with different properties than the feeding network or by introducing physical lengths elements that make the signal travel with different phase.

First, the system presented in the document [19] explains a system where a dielectric part is installed with the coaxial line network that goes to the dipoles. The coaxial line technology is air-filled line in this case, and a dielectric part is located between the inner conductor and the outer conductor of the coaxial lines. The physical effect creates the phase shift that the dielectric material has higher permittivity than air. Therefore, this effect will reduce the phase velocity of the propagation of the signal through the transmission line and create the phase differential when the dielectric part (9) moves through the coaxial lines. The next figure shows a phase shifter element with this technology [19]:

![Phase shifter diagram](image.png)

*Figure: 2.4: Phase shifter with air-filled coaxial cable for the feeding network and a dielectric part (9) that creates the phase shift [19].*
The input is the number 1 and the dielectric part that is installed between the two outputs is the element number 9. Both inputs and outputs are connected via a crossover lid (7). As the figure is presented, there is no phase change in of the outputs, since the dielectric element is placed in the middle of both outputs. If the dielectric part moves towards the output 2, this part will have more dielectric material than output 3 and the phase shift with respect to the input will increase. Since the output 3 would be filled with less dielectric material, the phase shift with respect to the input will decrease and the output 2 will lag the phase at the output 3.

Secondly, the technology of phase shifter in microstrip is presented. There are two different shifters explained in [20]: a reflective type and a switch line phase shifter.

A reflective type phase shifter is formed by a coupler terminated in variable reactance that make the signal reflect with a phase shift [20]:

![Figure 2.5: reflective type phase shifter [20].](image)

The switch line phase shifter has different delays depending on either lengths of the line or different lumped elements [20]:

![Figure 2.6: switch line phase shifter [20].](image)

### 2.3 Remote Control Unit

The last part of this chapter ends with the explanation of the RCU, which is the element that drives the phase shifter in antenna through mechanical interface so that the change
of the electrical downtilt is applied. The RCU is usually at the bottom of the antenna with the necessary mechanical components to make the phase shifter move into different configurations for several degrees of tilt. It can be either installed within the antenna system or as a separated part as it is showed in [21].

Besides the different technologies, the RCU is controlled and attached to the network through two different elements: Central Control Unit (CCU) or Portable Control Adapter (PCA) [22]. CCU is the main element, is within the base station and is inherent to the network layout; in order to fulfil the requirements at a certain moment the CCU is accessed by the Operational Maintenance Center so that the Operational and Maintenance processes are controlled with this link. On the other hand, PCA is a system that is not inherent to the design of the network and allows to be installed for portable applications such maintenance operations for temporary access. This system is described graphically in [22]:

![Diagram](image)

Figure 2.7: System to control the Remote Control Unit by PCA in a three sector base station.[22]

The figures describes 3 sector site where the elements that are connected to the antennas such a PCA, PCA notebook and Power supply are inside the site. The connection between PCA or CCU and the RCU is always the same considering the standard defined by AISG. In this case, the tilt is controlled locally since the PCA is dependent on the Notebook and the PCA software, so an installation and maintenance engineers should be present to supervise the process. However, it is also common to manage the RCU remotely by the operation and management network via local or wide area network [22].
3. METHODOLOGY OF SIMULATIONS

The simulations that will be presented in this work are held by a system-level simulator based on MATLAB, called LTE-a System Level Simulator [23]. In order to explain the characteristics of the simulator, the author references to the documentation where the functionalities of the tool are explained by the developers [24] and, in this chapter, some characteristics that concern to the simulations of this work are presented.

3.1 Overview of the simulator

First of all, a summary with the main features of the simulator is described. The LTE system level simulator evaluates the Downlink Shared Channel with different antennas and transmit modes by abstracting the physical layer with an accurate model for the estimation of the SINR [25]. The explanation of all the procedures of this simulation is too extended and it exceeds the aim of this chapter, so a series of characteristics as well as patterns and the main loop of the simulator are shown in order to introduce the basis. In order not to mention the continuous reference, this and part 3.2 are based on the explanation of the previous references [23] [24] [25].

The structure of the simulator is composed by a number of inputs to its link-measurement model, which is the abstracted part for calculating the SINR of each user at a certain moment and position. Following that, link-performance model achieves the output as throughput error rates and distribution measurements. The next figure shows graphically the structure of the simulator:

![Figure 3.1: structure of LTE-A system Level Simulator [25]](image)

The inputs are presented as a table for each simulation for the next chapters and results. Generally, the simulator is run by several transmission time intervals (TTI), where the
layout with a set of eNodebs as well as a certain distribution of UEs is considered and the channel for each UE will be calculated. The defined area is called Region of Interest (ROI), which is the area within the network where the user has to be for calculating the parameter for that user. The positions for the ROI are into a matrix in MATLAB where each position of the matrix contains a value for the path loss and shadow fading map and it coincides with the position of every user. The main loop of the simulator is presented with the following pseudo code format:

```plaintext
for each simulated TTI do
    move UEs
    if UE outside ROI then
        reallocate UE randomly in ROI
    for each eNodeB do
        receive UE feedback after a given feedback delay
        schedule users
    for each UE do
        1- channel state → link quality model → SINR
        2- SINR, MCS → link perf. model → BLER
        3- send UE feedback
```

When the UE feedback is sent, the rest of the output as bit error rate and distribution and the throughput are calculated in different traces. The simple inputs are presented as a table: the basic simulation settings that are applied are the network layout, geometry, distances of the network, UE distribution, antenna transmission, etc. From now on, we will focus on the parameters that concerns this work like the model of the antenna and the calculation of the SINR and the capacity.

The main input that has been added to the simulator is a new class for a new type of antenna in order to compare the tilt of two different real antennas. The 3D antenna modelling is presented in the documentation and it is based in the conventional model that is in [26]. This paper is aim at comparing the modeling of 3D antennas and, particularly, the LTE system-level simulator used takes into account the introduction of the data of both the vertical and the horizontal pattern so that the conventional method for a 3D pattern is applied:

\[ G(\phi, \theta) = G_H(\phi) + G_V(\theta) \] (3.1)

For each angle of tilt and frequency, the data from the measured antennas are implemented in its specific format for the azimuth and the elevation angle.
3.2 Calculation of SINR and capacity

As described before, the simulator utilizes an abstraction for the link level measurements and it calculates the so-called post equalization SINR [27]. This model is developed in order to quantify the quality of the received signal after reception and equalization. All this structure is very tedious and the explanation is summarized in the next figure presented in [27]:

![Diagram of physical layer abstraction for LTE system level modelling](image)

Figure 3.2: Physical layer abstraction for LTE system level modelling [27].

However, this post-equalization SINR (subcarrier SINR vector in the figure) is not the measure that will be presented in this work, since the first one is the parameter that the simulator calculates as the abstraction of the link level layer. Otherwise, the so-called wideband SINR is evaluated in order to calculate the strength of the signal that every user has within one certain cell considering other interferers. Therefore, the formula of this concept is given as follows:

$$
\Gamma = \frac{G_{\text{antenna,o-macro,0}P_{tx,0}}}{\sigma^2 + \sum_{l=1}^{N_{int}} G_{\text{antenna,l-macro,0}P_{tx,l}}}
$$

(3.1)

Where L macro is the multiplication of both path losses and shadow fading losses, G antenna is the gain of the antenna considering the previous model at a certain position, Ptxo is the transmitted power of the target base station, and $\sigma$ is the noise level for a certain bandwidth. Besides, in the simulations the shadow fading is not considered so the losses will be taken into account as path losses. The model for the path loss is COST 231-Hata Model for sub-urban areas, which is found in [1]:

17
\[ L = 46.3 + 33.9 \log f - 13.82 \log h_B - a(h_R) + [44.9 - 6.55 \log h_B] \log d + C \quad (3.2) \]
\[ a(h_R) = (1.1 \log f - 0.7)h_R - (1.56 \log f - 0.8) \]

Where \( L \) is the median path loss in dB, \( f \) is the frequency of transmission in MHz, \( h_B \) is the base station antenna effective height in metres, \( d \) is the link distance in km, \( h_R \) is the mobile station antenna effective height in meters, \( C \) is 0 or 3dB depending on the use of suburban or metropolitan areas, and \( a(hr) \) is the mobile station antenna height correction factor as described in the Hata model for urban areas.

Finally, the capacity for the results are as Shannon formula states:

\[ C = B \log_2(1 + SINR) \quad (3.3) \]

### 3.3 Model of energy efficiency

This chapter describes the simple model for energy efficiency results that has been selected. The aim is to show the model for the optimum tilt of each antenna and evaluate the energy metrics. This model for energy consumption and efficiency is taken from [28] where the theoretical model for the energy efficiency results is presented. First of all, the model for the power consumption of a base station has to be considered:

\[ P_{in} = N_{TRX}(\Delta p P_{tx} + P_o) \quad (3.4) \]

Where \( N_{TRX} \) is the number of base stations that are transmitting at the same time, \( \Delta p \) is the portion of the transmitted power consumption due to feeder and amplifier losses and \( P_o \) is the power that the base station consumes when it is turned on and put in the signalling mode. DTX means Discontinuous Transmission and this technology will not be considered in this work. Since the networks that will be considered in this work are macro cellular networks, the values of these parameters for the consumption of a base station will be taken for macro cellular for the next table [28]:

<table>
<thead>
<tr>
<th>Base Station Type</th>
<th>( P_{max} ) [W]</th>
<th>( \Delta p )</th>
<th>( P_o ) [W]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macro</td>
<td>40</td>
<td>2.06</td>
<td>118.7</td>
</tr>
<tr>
<td>Micro</td>
<td>6.3</td>
<td>3.1</td>
<td>53</td>
</tr>
<tr>
<td>Pico</td>
<td>0.13</td>
<td>4.2</td>
<td>6.8</td>
</tr>
<tr>
<td>Femto</td>
<td>0.05</td>
<td>7.5</td>
<td>4.8</td>
</tr>
</tbody>
</table>

Table 3.1. Power parameters

The aspects to be considered as energy efficiency metrics are two: energy in Watts per area and bit per Joule of the network.

The formula used to calculate the energy per area is the following [28]:

18
Where $P_{tot}$ will be the power consumption of one base station, since the users are for the central base station, and $A$ will be the area to get a minimum throughput by observing the 5th percentile throughput within different ISD.

On the other hand, the energy efficiency in terms of bit per Joule is shown in the next formula [28]:

$$\psi = \frac{C_{\text{net}}}{P_{tot}}$$

In order to assess this performance, the capacity $C_{\text{net}}$ will be the average throughput as the 50th percentile of the CDF throughput, and $P_{tot}$ is the total power consumption of the network for different ISD.
4. COMPARISON BETWEEN IDEAL AND REAL ANTENNAS

This chapter introduces the simulation for comparing two different real antennas and the simple model for horizontal pattern by 3GPP. In order to explain the difference when using distinct antennas, a 7 site scenario with a frequency reuse of 3 is simulated and the performance in terms of capacity and coverage are presented for three antennas.

4.1 Antennas

The first step is to enumerate the characteristics of every antenna that will be used. The terms that describes these antennas are the horizontal and vertical beamwidth, which is the width in degrees of the beam where the energy decreases 3 dB below the maximum gain; the maximum gain of the main gain, i.e. the maximum point of energy; and the different frequencies that the ports of the antenna support.

The three different types of antennas are the ideal model for 3GPP TS 36.942, the antenna provided by Cellmax CMAB 6521 with 65 degrees of horizontal beamwidth, a frequency range of 1800-2100 MHz and a vertical beamwidth at the frequency used of 3.9 degrees with a maximum gain of 21dBi, which will be referenced as antenna type 1; and the antenna from KATHREIN, the type 742212 with a frequency range of 1710-2170 MHz, a horizontal beamwidth of 63 degrees and a vertical beamwidth of 6.5 degrees at the aimed frequency with a maximum gain of 18dBi and will be called as antenna type 2. The next table summarizes the characteristics for this antennas:

<table>
<thead>
<tr>
<th></th>
<th>Antenna 1</th>
<th>Antenna 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>CMAB 6521</td>
<td>KATHREIN 742212</td>
</tr>
<tr>
<td>Frequency range</td>
<td>1800-2100 MHz</td>
<td>1710-2170 MHz</td>
</tr>
<tr>
<td>Maximum Gain</td>
<td>21 dBi</td>
<td>18 dBi</td>
</tr>
<tr>
<td>Vertical Beamwidth</td>
<td>3.9</td>
<td>6.5</td>
</tr>
<tr>
<td>Horizontal Beamwidth</td>
<td>65</td>
<td>63</td>
</tr>
</tbody>
</table>

Table 4.1: Antenna features

The previous data matches with the frequency of 2130 and 2140 MHz respectively at which the simulations are fulfilled. Besides, the patterns for 3 antennas are presented in the following figures in order to see the difference of the energy transmitted at every direction:
Figure 4.1 Horizontal and Vertical antenna Patterns

It is noticeable that the ideal antenna only represents the horizontal radiation pattern and the other two real antennas will be implemented by the 3D antenna model previously presented.

4.2 System Level model

The quantification of the performance of different antennas is the aim of this chapter. It is important to observe the behaviour of antennas with different characteristics in order to measure how accurate ideal antennas can be. Besides, the difference of the pattern is reflected in some parts of the network.

This simulation takes place over a network with 7 sites where each site is divided by 3 sectors or cells with a hexagonal shape and with frequency reuse of 3. Moreover, the users are distributed uniformly over the cells, with a constant number of UE per cell. The rest of inputs to the simulator are presented in the next table:
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of eNodeBs</td>
<td>21 (7 sites, three sector)</td>
</tr>
<tr>
<td>Frequency</td>
<td>2 GHz</td>
</tr>
<tr>
<td>Intersite distance</td>
<td>2000 m</td>
</tr>
<tr>
<td>UEs per eNodebs</td>
<td>20</td>
</tr>
<tr>
<td>UE distribution</td>
<td>Constant UE per Cell</td>
</tr>
<tr>
<td>Pathloss model</td>
<td>COST 231 – Hata Model, urban macro</td>
</tr>
<tr>
<td>Shadow fading</td>
<td>none</td>
</tr>
<tr>
<td>Minimum coupling loss</td>
<td>70 dB</td>
</tr>
<tr>
<td>Antennas (Tx - Rx)</td>
<td>2x2</td>
</tr>
<tr>
<td>MIMO mode</td>
<td>CLSM</td>
</tr>
<tr>
<td>Tx power</td>
<td>40 W</td>
</tr>
<tr>
<td>Total Bandwidth</td>
<td>20 MHz (100 RB)</td>
</tr>
<tr>
<td>Noise spectral density</td>
<td>-174 dBm/Hz</td>
</tr>
<tr>
<td>Simulation length</td>
<td>30 subframes (TTI)</td>
</tr>
<tr>
<td>Scheduler algorithm</td>
<td>Round Robin</td>
</tr>
</tbody>
</table>

Table 4.2: Simulation parameters

### 4.3 Results

As it has been mentioned, taking into account a factor reuse of 3 a mapping of the SINR values of the central 3-sector site is presented, which is limited to 15 dB as the ‘y’ axes indicates and shows how the values of SINR of each cell are distributed. This SINR values are measured as the maximum SINR value from the target base station at one point minus the second highest SINR from the most interfering base station, which represents a map of SINR difference and at the same time it shows how powerful the signal of the target cell for each point is. It is observable that the ideal antenna pattern has no areas without radiation, but actual antennas show drops of energy where no energy is transmitted and that can be noticed with a narrower influenced zone of high values of SINR. On the other hand, high directional values of SINR cover more area with actual antennas, this is, in the zone closer to the edge, because of the maximum gain of 21 dBi is higher than 15 dBi of 3GPP antenna.
With this first overview the results of the cumulative distribution function of the average wideband SINR of all the users of the network has been calculated for each of the types of antenna. The above graph of the figure 4.3 is the CDF over the SINR average values, and the second figure the CDF is analysed by separating the percentage of UEs that are in a range of value of SINR, in this case it is considered as limits 10 and 20 dB.
These result reflects, generally, that there is margin of 10% of difference as the maximum on some of the intervals between antenna 2 and 3GPP, which means that to measure the average SINR wideband of all the users the difference of the radiation patterns does not turn into divergent results. However, inspecting the performance of each UE of the central site it is noticeable how the UEs that are situated away from the antenna in the direction of the main lobe are the only ones that obtain more SINR using real high gain antenna than ideal 3GPP antenna:

![Figure 4.4: UE that are most influenced by the signal of real antennas for the centre cell](image)

This means that high gain antennas show better performance on defined locations around the main lobe and close to the edge, which will be useful to next step of this research on LTE antenna tilting, since this area will be the most affected by the influence of the main lobe of the antennas and, thus, these real high gain antennas will be evaluated. On the other hand, the rest of the users that are spread over the sector obtain better SINR values with 3GPP antenna since the pattern is ideal and there is no drops of energy in the radiation pattern.

Finally the same study is fulfilled for the CDF of the throughput of all users showing a similar variation with respect to the previous study of SINR:
The results show the same difference; that is the use of an ideal antenna is a good approximation when evaluating the whole network in terms of capacity as well.

In order to sum up the ideas from the previous results are summarized in the next points:

- In the first part the results of a system level performance simulation with ideal 3GPP antenna and real high gain antennas have been presented and compared.
- The parameter that have been assessed in detail is the SINR values over the whole network and the results show that ideal antenna can be suitable for a general view of the system level performance since the difference is not remarkable. In terms of percentage the variation is 10% of the users in certain measurements as the maximum.
- Ideal antenna without drops of energy in the radiation pattern makes the users that are distributed randomly obtain a better average SINR.
- However, SINR areas differ and real antenna shows better performance close to the edge, where the difference in main lobe is more significant.
The next step will be to assess the tilt of the antenna, where actual high gain antennas will be evaluated. The influenced area of the change of the tilt will be around the edge of the cells.
5. SIMULATION OF TILTED ANTENNAS

This section contains the final results of the thesis, where the tilt of the antennas is evaluated within a macro cellular scenario. The main goal of the part is to go through the two remaining research questions, which are presented hereby.

First of all, the evaluation of the effect of remote electrical tilting on system-level simulations is to be done, which brings to the following question: What is the improvement of tilt optimization and which is the optimum angle considering the effect on coverage and capacity in a macro cellular network and two different real antenna radiation pattern within various ISD?

Secondly, the energy efficiency evaluation will take place in order to answer the question: What are the energy efficiency values when the optimum tilt is applied for both antennas?

Finally, the radiation patterns of the antenna are the main interest, since remote electrical tilt performance in real cases makes both horizontal and vertical antenna pattern change significantly. Thus, the next question comes up: When tilting the antenna, how do changes in the radiation patterns affect the received signal in each of the antennas evaluated?

In order to answer these questions the chapter is subdivided in three sections, where the previous points will be addressed respectively.

5.1 Antennas and System Model

The first simulation is performed with similar characteristics to the previous one: with a reuse factor of 3, 20 MHz as the bandwidth for the whole network and the users are distributed uniformly over the entire network. In this case the antenna type 2 is the same as the previous one, but the antenna type 1 is changed in order to find antennas with similar values of RET in order not to limit this parameter.

The antenna type 1 that has been chosen is the CMAB-6520 with a RET that goes from 0 to 8 degrees, with a range of frequencies of 1710-2170 MHz and the maximum gain of 19.5 dBi. The next table compares the two selected antennas:

<table>
<thead>
<tr>
<th></th>
<th>Antenna 1</th>
<th>Antenna 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>CMAB 6520</td>
<td>KATHREIN 742212</td>
</tr>
<tr>
<td>Frequency range</td>
<td>1710-2170 MHz</td>
<td>1710-2170 MHz</td>
</tr>
<tr>
<td>Maximum Gain</td>
<td>19.5 dBi</td>
<td>18 dBi</td>
</tr>
<tr>
<td>Vertical Beamwidth</td>
<td>5.4°</td>
<td>6.5°</td>
</tr>
<tr>
<td>Horizontal Beamwidth</td>
<td>65°</td>
<td>63°</td>
</tr>
</tbody>
</table>
Remote Electrical Tilt | 0°-8° | 0°-8°
---|---|---

Table 5.1: Antenna characteristics for simulations

The same network is utilized for every tilt iteration, i.e. for the same number of eNodebs, ISD and UE the simulations are run to calculate the coverage and capacity results. Besides, the tilt is applied in every antenna of the system: for each iteration of tilt, the antennas of the whole network have the same configuration. The next table shows the rest of important parameters to run the simulation:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of eNodeBs</td>
<td>21 (7 sites, three sector)</td>
</tr>
<tr>
<td>Carrier frequency</td>
<td>2 GHz</td>
</tr>
<tr>
<td>Intersite distance</td>
<td>2000 m</td>
</tr>
<tr>
<td>UE distribution</td>
<td>Uniformly</td>
</tr>
<tr>
<td>Pathloss model</td>
<td>COST 231 – Hata Model, urban macro</td>
</tr>
<tr>
<td>Shadow fading</td>
<td>none</td>
</tr>
<tr>
<td>Minimum coupling loss</td>
<td>70 dB</td>
</tr>
<tr>
<td>Antennas (Tx - Rx)</td>
<td>2x2</td>
</tr>
<tr>
<td>MIMO mode</td>
<td>CLSM</td>
</tr>
<tr>
<td>Tx power</td>
<td>40 W</td>
</tr>
<tr>
<td>Total Bandwidth</td>
<td>20 MHz (100 RB)</td>
</tr>
<tr>
<td>Noise spectral density</td>
<td>-174 dBm/Hz</td>
</tr>
<tr>
<td>Simulation length</td>
<td>30 subframes (TTI)</td>
</tr>
<tr>
<td>Scheduler algorithm</td>
<td>Round Robin</td>
</tr>
<tr>
<td>Antenna height</td>
<td>32 metres</td>
</tr>
</tbody>
</table>

Table 5.2: Simulation parameters
5.2 Coverage and Capacity Measurements

The evaluation of coverage and capacity is the main measurement for the presentation of these results. For that matter, the coverage is considered as two values of the CDF of the previously showed SINR: 5th percentile and 50th percentile of the CDF of the SINR for the coverage at the cell edge and average SINR respectively.

On the other hand, the capacity of the network is considered by 3 terms: cell edge (5th percentile), average and peak throughput (95th percentile) of the network respectively. Considering the average throughput, this is the arithmetic mean value of the users considered, which are the ones in the centre site (3 centre cells). It is important to notice that this value depends on the bandwidth that each user receive from the scheduler round robin. In this case 20 MHz (100 Resource Blocks) are shared equally for the average users per cell, which are approximately 25 users per cell. Therefore, the mean Resource Block for each users is 4.
Moreover, the figures that will be showed correspond with the users in the site at the center of the network, so 3 center cells are the evaluated cells, since the interference is created by the ring of 6 sites around it.

Then, the all the results with all the different iteration of the remote electrical tilt and comparing both antennas in order to solve the research question: “What is the improvement of tilt optimization and which is the optimum angle considering the effect on coverage and capacity in a macro cellular network and two different real antenna radiation pattern?” Therefore, with this research, the improvement of tilt optimization is calculated and after, in the next part, the radiation pattern and the relationship with the tilt optimization is analysed.

![Graph](image)

**Figure 5.2:** 5th and 50th percentile of SINR with different tilt degree for UE of the centre cell.

In terms of coverage, with the exposed graphics it is noticeable that remote electrical tilt increases both the average and cell coverage (5th and 50th percentile) until the optimum tilt degree, which is the same for both antennas. This is logical because if the electrical downtilt is 7-8 degrees, the inclination of the energy is so high that the edge of the cell is
not covered anymore and the performance on SINR in these users decreases significantly. Regarding the presented data and taking into account the improvement from the state of no tilt, – 0 degrees of tilt- the results show that for the 5th percentile of SINR it is possible to increase up to 18% for antenna 2 and 32% for antenna 1; then, for the 50th percentile of SINR the tendency is to increase the performance as well, with the 30% of increasing performance for antenna 2 and 50% for antenna 1, within the same degree of optimum tilt angle for both of them.

Therefore, these results show that electrical downtilt greatly improves the performance of coverage, especially for the worst-case users which are considered to have the least coverage on the network, i.e. the 5th percentile of the average SINR. In addition, there is a difference in the behaviour of the tilting between the two selected antennas, with different performance for the optimum tilt. Moreover, antenna 2 shows better coverage for 0 and 1 degrees of tilting and as the applied tilt takes place, antenna 1 increase the tendency and get better results for the optimum tilt of 3 degrees.

The next step of the results is the effect of the tilt in capacity terms, which brings to show the next graphics, following the same methodology as before, but taking into account average throughput:
This time, considering the previous graphs of the capacity measurements, the same tendency can be seen in the coverage results, i.e., there were significant improvements when applying electrical downtilt in all aspects - edge, peak and average cell throughput. It is described each of these aspects in the following.

Firstly, cell edge throughput (5th percentile) is discussed and it can be observed that electrical downtilt improves the performance up to a certain degree, when all the users near the edge start receiving a reduced signal as the tilt is increased to aim at areas closer to the base station. With moderated degree of tilt, the improvement is, taking the reference the no tilt state for each antenna, up to 40% for antenna 2 and 50% for antenna 1.

Secondly, average cell throughput has the same tendency as cell edge except for the fact that the high level of tilt makes the average throughput decrease with less intensity than cell edge throughput does, which is reasonable since this is the 50th percentile and it is the average of the users. The improvement will be assessed by taking the optimum degrees of tilt for the cell edge users, and, as a result, for antenna 2 the improvement is 25% and 33% for antenna 1.

At last, peak cell throughput shows an increasing tendency within all different grades of tilt, which is reasonable since this measure can be taken as the users that are closer to the base station, and every time the antenna is tilted, the energy will be pointed to areas closer to the base station. However, there is a compensation between peak cell and cell edge measurements and, since the optimum tilt for cell edge users also improves peak cell edge, the improvement will be assessed with these angles. Therefore, for antenna 2 the performance increases by 40% and for antenna 1 it does by 38%, both of them being tilted by 3 degrees.

Finally, in the next table there is a summary with the measurements obtained so that they can be checked more clearly:
In addition, the next table shows the values in percentage of the improvement of antenna 1 network performance in comparison with antenna 2 for the optimum tilt of 3 degrees:

<table>
<thead>
<tr>
<th>Coverage</th>
<th>Average Throughput</th>
<th>Coverage</th>
<th>Average Throughput</th>
</tr>
</thead>
<tbody>
<tr>
<td>5th-centil</td>
<td>Pea</td>
<td>Averag</td>
<td>Edg</td>
</tr>
<tr>
<td>18%</td>
<td>30%</td>
<td>40%</td>
<td>25%</td>
</tr>
</tbody>
</table>

Table 5.3: Improvement of optimum tilt in coverage and capacity

From these results it can be emphasized the next points:

- Tilt adjustment is an important factor that can improve the performance of the network in terms of coverage and capacity.
- Coverage is dramatically affected by tilting, and the improvement of this field was very pronounced. The difference was noticeable between the two antennas, due to the high gain of antenna 1 and will be described in the following part with respect to the radiation pattern of both antennas.
- Capacity is a factor that is also improved with tilt adjustment. However, an important observation is found because not all the aspects of capacity change in the same way. That is, when optimum tilt was found for cell edge users, this is used for the average and peak capacity because of the significant increased values of these measurements, even though other angles may be optimum for the latter.

The next step is to define the same scenario as before with different inter-site distance (ISD). The purpose of this calculation is to see how the optimum tilt varies as the ISD changes and evaluate what is the difference of performance between both antennas for the optimum tilt in each ISD. The consideration of this simulation has been for macro cells so that the ISD will vary between the minimum of 500 metres and 2000 metres and the same antennas with the same remote electrical downtilt are applied to the network.
First of all the next figure will represent how the tilt changes as several ISDs are applied to the simulations:

![Optimum Tilt with Different ISD](image)

**Figure 5.4:** Optimum degree of tilt for different ISD for both antennas

The explanation of this figure starts with the fact of the decreasing tendency of the optimum tilt as the ISD is higher, that is, with larger area to cover. This is logical, since the bigger the area to cover, the less amount of tilt it can be applied due to the lack of coverage when the downtilt is so high that the area cannot be satisfied. On the other hand, small areas are covered when the tilt is at the maximum of 8 degrees and there is different optimum tilt for each antenna and different inter-site distance. However, it is noticeable that for 500 metres the optimum tilt is the same as for 1000 metres. This means that for small cells RET is limited since a larger tilt or a combination with mechanical tilt change would be necessary for optimizing the network.

The performance of each of the presented optimum tilt has been calculated and with the next figure it is seen the percentage of improvement in the performance for coverage as the 5th percentile of SINR and cell edge capacity as the 5th percentile of the CDF throughput.

![5th Percentile SINR vs ISD for Optimum Tilt](image)

**Figure 5.5:** Coverage for different ISD and the optimum tilt for both antennas
In these figures it is again observable the fact that for 500 metres the RET is limited since it does not follow the tendency of optimization. In this case mechanical downtilt should be applied. Besides, it is noticeable that antenna 1 shows better performance when tilted. For the 0 tilt and 1 degree tilt the performance is similar and antenna 2 even shows better results. The last section will explain why this behaviour happens, that is, why antenna 1 as better performance when they are tilted from 2 degrees forwards.

### 5.3 Energy efficiency measurements

For every optimum tilt and ISD, the energy efficiency results are studied with the theoretical basis explained in chapter 3. The research question to answer is the next one: What is the energy efficiency values when the optimum tilt is applied for both antennas? The measurements to evaluate energy efficiency will be the metrics in Watts per area and Bits per Joule.

First of all, the study of the energy efficiency in terms of Watts per area will be taken as mentioned in previous chapters, \( \Omega = \frac{P_{\text{tot}}}{A} \). In this formula, \( P_{\text{tot}} \) will be the power consumption of one base station, since the users are for the central base station, and \( A \) will be the area to get a minimum throughput by observing the 5th percentile throughput within different ISD. The data will be considered from figure 5.6, where the needed area for various throughput values is calculated so that different areas are necessary for different aim throughputs. The area is calculated with the cell radius, which is known due to the reuse factor of 3 and the intersite distance. With the cell radius, the area of a cell will be calculated as [29]:

\[
R = \frac{ISD}{3}
\]
\[ A = \frac{3\sqrt{3}}{2} R^2 \]

Since there is only one base station considered, the power consumption of one base station over the area for each throughput value is taken into account to calculate the next graph about power per area:

![Base Stations per km²](image1)

**Figure 5.7:** Number of base stations per area required for a certain level of cell edge throughput

![Power per Area](image2)

**Figure 5.8:** Power per area for different level of cell edge throughput

These results show how both the power consumption per area and the base stations per area increase with a minimum range of throughput required. Both antennas are compared.
with their optimum tilt respectively, which turns out in different energy efficiency metrics for different tilts and antennas.

The last calculation to be made is the energy efficiency in terms of bit per Joule. In order to assess this performance, the average throughput as the 50th percentile of the CDF throughput is taken into account, as well as the evaluation for different inter-site distances. The calculation is made with the next formula presented before $\psi = \frac{C_{\text{net}}}{P_{\text{tot}}}$. The considered power will be the same as before for one base station and the aggregate capacity is regarded as the average throughput. The next graph is presented in order to calculate the energy efficiency with different intersite distance:

![Energy efficiency kbit/Joule](image)

**Figure 5.9**: kbit per joule for the optimum tilt in every intersite distance

This figure shows how the tilt optimization improves energy efficiency, i.e. more bits per Joule with the optimum tilt measurements as well as with small cells the efficiency is higher than with bigger cells. This explains that remote electrical tilt finds better energy efficiency results when the optimization is utilized in smaller cells. The results are for average capacity and this parameter varies less when tilting and that can be observed in the small difference between the energy efficiency parameters of both antennas.
5.4 Changes in the radiation pattern when tilting

The radiation pattern changes when the RET is applied to the antenna. The study of these changes is made by examining the two cuts of the pattern, i.e. the vertical or elevation pattern and the azimuth pattern. This chapter explains how the patterns affect the received power in the base station cells.

5.4.1 Vertical Pattern

There are several characteristics that are in the requirements and the standards for the shape of the base station antennas. This text will focus on three factors mentioned in [30]: the null fill and the first lower side lobe, which are the level of power gain just below the main lobe and affect to the areas closest to the base station; the gain of the main lobe and the roll-off, which will affect to the cell edge received power; and the upper-side lobe peak to 20°, that is the level of suppression of the maximum side lobe above the main one considering 20° up the main lobe and it will interfere the next cells when tilt is larger by combining remote an mechanical tilt.

The radiation pattern for 0°, 3° and 6° are presented and the variation of the lower side lobe and the upper side lobe peak to 20° with respect to the tilt are described. In order to explain how the side lobes and the main lobe with the gain and the roll off affect to the received signal in the cell, a model with the previous path loss COST 231-Okumura hata and the received power for every distance from the base station is presented. The following figures show the radiation pattern for 0°, 3° and 6°.
Figure 5.10: Vertical Pattern for 0°, 3° and 6° of tilt for each antenna

The main characteristics considering the gain and the roll off is that antenna 1 maintains a sharper inclination of the roll off as well as the difference of the peak gain also is noticeable. This will be described in the following figures about the received power.

The first figure shows what the elements to take into consideration are. SLL1 corresponds with the lower side lobe just after the main lobe and SLL2 corresponds with the peak side lobe taking the range of 20° from the main lobe. The next graphs will show the variation of SLL1 and SLL2 when RET is applied from 0° to 8°:
Figure 5.11: Variation of lower side lobe level and upper side lobe level peak to 20º for each antenna at every tilt iteration.

The first graph shows how the first side lobe and, as a consequence, the null fill as previously described as well, is higher for antenna 1, that is, the side lobe level is lower at each tilt iteration. That means that the power for the areas closer to the base station are higher for antenna 1. On the other hand, the SLL2 corresponds with the upper side lobe level that creates interference to the next cells. The analysis shows that antenna 1 has lower SLL2 and, thus, the upper side lobe is higher than antenna 2, which will convert into more interference as we will see in the next graphs.

As it was explained, the next graphs show the received signal in dBm with respect to the distance for the path loss model Okumura Hata-COST 231 presented in the previous chapter and a transmission power of 46 dBm. Thus, it is an emulation of the previous simulation for one base station to evaluate how the received power change with the variation of the distance. The figures show the performance of the antennas for 0, 3 and 6 degrees and the cell range is presented as a red line for a base station that covers a cell with an inter-site distance of 2000 metres.
Figure 5.12: Received Power for a site with different antennas with respect to the distance. 0º, 3º, and 6º of tilt for each figure respectively.

The figures describe, on the one hand, the better performance for the optimum tilt of 3 degrees as the previous simulations showed. The high gain of the antenna 1 (blue line) and its sharper roll off makes the effect of the tilt more intense. This is the reason why for 6 degrees the inclination is so intense that it does not cover the cell anymore and this confirms the previous results for 2000 metres of ISD, where the antenna 1 decreased the performance from 6 degrees of tilt. Thus, the sharpness of the roll off explains the difference between the optimum tilt for different ISD: antenna 1 has a sharper roll-off and the effects of tilt changes are stronger and, as a result, it is necessary less degrees of tilt to optimize the performance of the network when the ISD changes. Besides, the previous explanation in combination with the difference of 1.5 dB in the maximum gain of the main beam make the effect of the tilt of antenna 1 deeper.
The other parameter that is noticeable in the figures above is the lower side lobe, which is the second peak of energy just before the main peak. This power is received by the users that are closest to the base station and the figures show how this peak is bigger for antenna 1 (blue line) as the tilt is applied.

Finally, in order to evaluate the upper side lobes and the interference that is created in the adjacent cell the same figures as above are presented, but including a mechanical tilt of 8 degrees, so that the influence of those lobes are presented. Besides, the cell range is reduced since this configuration is more common for smaller cells, and the red line is set by 200 metres. Although these lobes are not relevant in the previous simulation because a reuse factor of 3 was used and the adjacent cells was not interfered by each other, it is very important for networks with reuse factor of 1 and it is described below:

5.4.2 Horizontal Pattern

Lastly, and by knowing that both vertical and horizontal radiation pattern have influence in the 3D radiation pattern that is used in this simulation, the latter is presented for both antennas and different tilts (0, 3, 6 and 8 degrees), where the figures and the relationship with the coverage and capacity results are analysed:

![Figure 5.13: Received power for both antennas by adding 8 degrees of mechanical tilt to 6º of RET.](image-url)
From the last figures the main difference is the amount of the change of the horizontal radiation pattern in each iteration, i.e. it is very perceptible that the pattern of antenna 2 have sharper changes than antenna 1, where at every tilt the change is softer. This also coincides with the variation of the previous values, since the tilt optimum degree is 3 for antenna 2 and 6 for antenna 1 and for values more than 3 the tilt adjustment shows no improvement in the case of antenna 2. Therefore, this manifests less distortion that the remote electrical tilt mechanism makes into the horizontal radiation pattern, the better performance in each iteration of tilt it will be obtained.
6. DISCUSSION AND CONCLUSIONS

In this work the remote electrical tilt (RET) of real antennas has been evaluated by examining the effect of coverage capacity and energy efficiency on LTE networks. Besides, the changes of the radiation pattern of different antennas is examined and its effect of the received signal of a site when the tilt is applied.

In the introductory part, the background of the topic is presented, where it is shown how important the tilt of the antenna is in order to improve the performance of the network when the population moves and the areas of influence of the cell have to be modified. Besides, the distortion of the pattern when the antenna is tilted is presented and the found problem is described when simulations and analysis of real antenna patterns are necessary because of the several changes in the radiation pattern. Hence, it is shown why the simulation of real antenna pattern is important and relevant. Moreover, the related work and the importance of remote electrical tilt on Self Organizing Networks and coverage, capacity and energy studies are described as well.

Following that, the basis of the Remote Electrical Tilt within the antenna is presented in order to understand how this mechanism work. The theoretical principles of phased shift arrays as well as different technologies of phase shifters are explained too. There is also a brief extension of the role of RET and its connection with the rest of the network, i.e. the Remote Control Unit is presented. Following that, the methodology of the simulations is analysed by explaining the functionalities of the LTE Downlink System level Simulator that has been used during the whole document.

The following chapter presents the results for a system level simulation of 3 different antennas, two antennas with real patterns and the ideal model of 3GPP. The aim is to analyse the difference in terms of coverage and capacity when using each antenna. With the established scenario, measurements show that there is a variance of 10% at maximum in the results obtained and, as a result, it is a good approximation of the ideal 3GPP antenna. However it is significant to mention that the imperfections of the patterns of real antennas as well as its higher gain, makes the users close to the edge receive better performance than the ideal antenna. On the other hand ·3GPP ideal antenna has a wider influence in the cells and shows better performance in the whole network.

Finally, the concluding chapter is the main part of the work, since all the research questions are answered in this part. Two different real antennas are compared and the results in terms of coverage and capacity shows that tilt can improve up to 50% for cell edge throughput and 32% in terms of coverage for a macro cellular network. However, improvement of tilt is different for both antennas, showing that different real pattern does not achieve similar results.

In addition, the same simulations are run for different inter site distances in order to find the optimum tilt for each antenna. Results show two main points: both antennas have
different optimum tilt when the size of the cells changed, and for the smallest size remote electrical tilt is not enough to optimize the network and mechanical tilt would be needed, since the coverage results are similar for 500 and 1000 metres for the optimum tilt.

Following that, the energy efficiency results are presented for the optimum tilt at each ISD. The results show that the optimum tilt influences more for antenna 1 than for antenna 2; which means that the effect of tilting is also higher in energy efficiency metrics.

Finally, the antennas are evaluated with respect to the pattern for each degree of tilt. A tool that calculates the received signal helps evaluate the effects of the vertical pattern over a base station.

Results show that there are three elements that affect the received signal close to the base station, cell edge received signal and interference signal, respectively are the lower side lobe, the roll-off and the high gain of the main lobe and upper side lobe. Results show that antenna 1 has sharper roll-off and higher gain at each iteration of tilt and that makes the cell edge coverage improve as well as the impact of the tilt is higher. In addition, antenna 1 has better received signal in areas close to the base station due to the low side lobe level below the main lobe, confirming the previous results that showed better peak throughput in this case. Lastly, it is observable that the side lobe level above the horizon are higher for antenna 1 and a new graph is created with mechanical tilt to assess such a behaviour. The results show that at every tilt iteration the interference that antenna 1 creates on the adjacent cell is higher than antenna 2.

About the horizontal pattern, it is shown how the antenna that has more distortion in the horizontal pattern showed worse performance in the results showed in the part 5.1 and 5.2.

Therefore, these characteristics of the antennas that have been analysed are very important factors to be considered to install the antenna in a certain deployment. Operators and manufactures can find in this work some key factors for systems where remote electrical tilt is applied. Antennas with apparently similar characteristics can give different performance as it has been showed. Thus, all the pointed features of the antenna have to be considered as the elements that can affect different parts of the system.

Therefore with all the collected analysis, the next points are the most relevant:

- Electrical tilt is a crucial factor that improves capacity coverage within macro cellular networks; especially with results in the edge of the cell.
- Optimum tilt changes with the size and the antenna used, because of the differences of the radiation pattern.
- Energy efficiency varies depending on the optimum tilt and the size of the network, therefore depending on the antenna chosen; the energy savings can be obtained.
The vertical and horizontal pattern significantly affect the received signal of the base station. Those characteristics should be considered when the antenna is implemented.

Possible limitations

The limitation that this work presents is the absence of more possible tilt; for instance, adding mechanical tilt for smaller cells. This factor affects the optimization of the small cells because their performance cannot improve for the height and tilt presented.

Besides, there is no inter-cell interference due to the reuse factor of three, so the effects of the upper lobes are not taken into account in the simulations. This also means that the level of interference between adjacent cells is considered in this work.

Lastly, the users are considered to be uniformly distributed in the network, which can be a limitation, since different distribution with hotspots could represent better results because certain areas could examined.

Future work

There are several points that can continue the work presented. The simulations are run for macrocellular scenario so it would be suitable to test heterogeneous scenario with small cells and assess the effect of tilt in those networks.

Besides, different user distributions could be set in order to evaluate the cell edge effects, i.e creating hotspots near the edge of the cells can improve the accuracy of results for the measurements of coverage. Moreover, this issue can be related to load balancing by examining how the users switch cells when the tilt is applied.

Finally, the work can be extended in terms of energy consumption metrics. A deployment with heterogeneous networks that can be tilted is interesting because of the possibility of turning on and off base stations. This scenario can be introduced because the tilt effect can leave base stations without users or with a very low quantity of users to provide service. Therefore, these base stations can be either turn off or reduce the power of activation because of the low load of users.
REFERENCES


[10] 3GPP technical report3GPP TR 32.804 V6.2.0 (2005-06)3rd Generation Partnership Project;Technical Specification Group Services and System Aspects;Telecommunications management;Remote control of Electrical Tilting (RET) antennas;Requirements (Release 6)


[23][Online]. Available: http://www.nt.tuwien.ac.at/ltesimulator/

[24] Vienna Simulators LTE-A Downlink System Level Simulator Documentation, v1.8r1375 Institute of Telecommunications Vienna University of Technology, Austria Gusshausstrasse 25/389, A-1040 Vienna, Austria


[27] Josep Colom Ikuno, Stefan Pendl, Michal Simko, Markus Rupp. *Accurate SINR Estimation Model for System Level Simulation of LTE Networks*. Institute of
Telecommunications Vienna University of Technology, Austria Gusshausstrasse 25/389, A-1040 Vienna, Austria


