Aalborg University

Network Optimization Through Antenna Tilting

Central Copenhagen Case Study

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Abstract:

Due to continuous improvements in mobile communication related to the performances of both networks and user equipments, network optimization and evolution have come into focus. Antenna tilting is one of the possible methods that can be used to achieve improvements in network performance, without the need of purchasing any new equipments. The main idea of this work is to investigate some automatic procedures for finding an optimum tilting angle value configuration of a network. Firstly, a theoretical overview of the problem has been carried out. Then, the analyzed scenarios and the simulation tool have been introduced. Finally, three methods of automatic antenna tilting have been presented and investigated through a case study of central Copenhagen. The performance of the different algorithms was then analyzed and the best algorithm was identified.

Preface

The present project is written in order to fulfill the academic requirements of the Master of Science in Telecommunication Engineering at Politecnico di Bari (Italy).

The project consists of a main report with a brief overview on the theory behind the network planning issue most focused on antenna tilting, information on the proposed methods, results of the simulations and discussions and conclusions of the research.

The work was carried out in the period between November 1st, 2008 and June 12th, 2009 at the Radio Access Technology Group (RATE) section, Department of Electronic Systems of the Aalborg University (Denmark). It accounts for 30 ECTS.

The author would like to thank the Supervisors, Full Professor and Principal Engineer in Nokia Siemens Networks (NSN) Preben Mogensen and PhD fellow and Engineer in NSN Gilbert Micallef. Further, the author would also like to thank Francesco, Txema and Carles for the essential support they offered before, during and after this long experience.

Finally, the author would like to notably thank his family: without them nothing could have been possible.

Giuseppe Cammarota

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Abbreviations

2G	Second generation
3G	Third generation
AMC	Adaptive modulation and coding
BS	Base station
CDF	Cumulative distribution function
CDMA	Code division multiple access
COST	European cooperation in science and technology
DLTP	Downlink throughput
FDMA	Frequency division multiple access
FM	Furthermost point
FN	First notch
HARQ	Hybrid automatic repeat request
HSDPA	High speed down link packet access
HSPA	High speed packet access
HSUPA	High speed uplink packet access
LCB	Largest common border
LTE	Long time evolution
MIMO	Multiple input multiple output
MS	Mobile station
POI	Point of interest
QAM	Quadrature amplitude modulation
QPSK	Quadrature phase shift keying
SINR	Signal to interference plus noise ratio

SNEPA	System and network planning
TDMA	Time division multiple access
UE	User equipment
UMTS	Universal mobile telecommunication system
Wi-Fi	Wireless fidelity

1. Introduction

During the last years we have witnessed huge developments and improvements within communication technologies. Since the commercial introduction of mobile communication, these improvements have taken us through a number of ‘generations’ developed for making communication more efficient and provide users with a better experience. GSM (Global System for Mobile Communication), also referred to as 2G, is the most well known and used standard worldwide.

The standards that follow GSM include UMTS (Universal Mobile Telecommunication System) and LTE (Long Term Evolution). The improvements of a new standard over its predecessors are clearly visible. Among others, such improvements can be noted by looking at the growth in achievable data rates. The adoption of new standards have increased data rates within all kinds of communication technologies.

Figure 1.1 [**1**] shows the growth in date rate supported by wired, nomadic and wireless technologies over the last thirty years. The term nomadic refers to a communication technology, such as Wi-Fi, that can be used while moving within a confined area but is not fully mobile [**1**].

The three trends shown by Figure 1.1, follow what is referred to as Edholm’s law: their data rates for each curve follows a similar exponential curves, with the slower technology trailing the others by a specific time lag. It is however interesting to note that, by extrapolating forward, a convergence between the data rates of nomadic and wireless technologies is expected at around 2030. Perhaps that is not too surprising, since both rely on the same core technology, radio [**1**].

Focusing on the wireless industry, both mobile network operators and vendors have felt the importance of efficient networks with equally efficient design [**2**]. An up-to-dated and optimized network allows network operators to offer their customers a better service while also the ability to support the addition of new customers, expanding their own business.

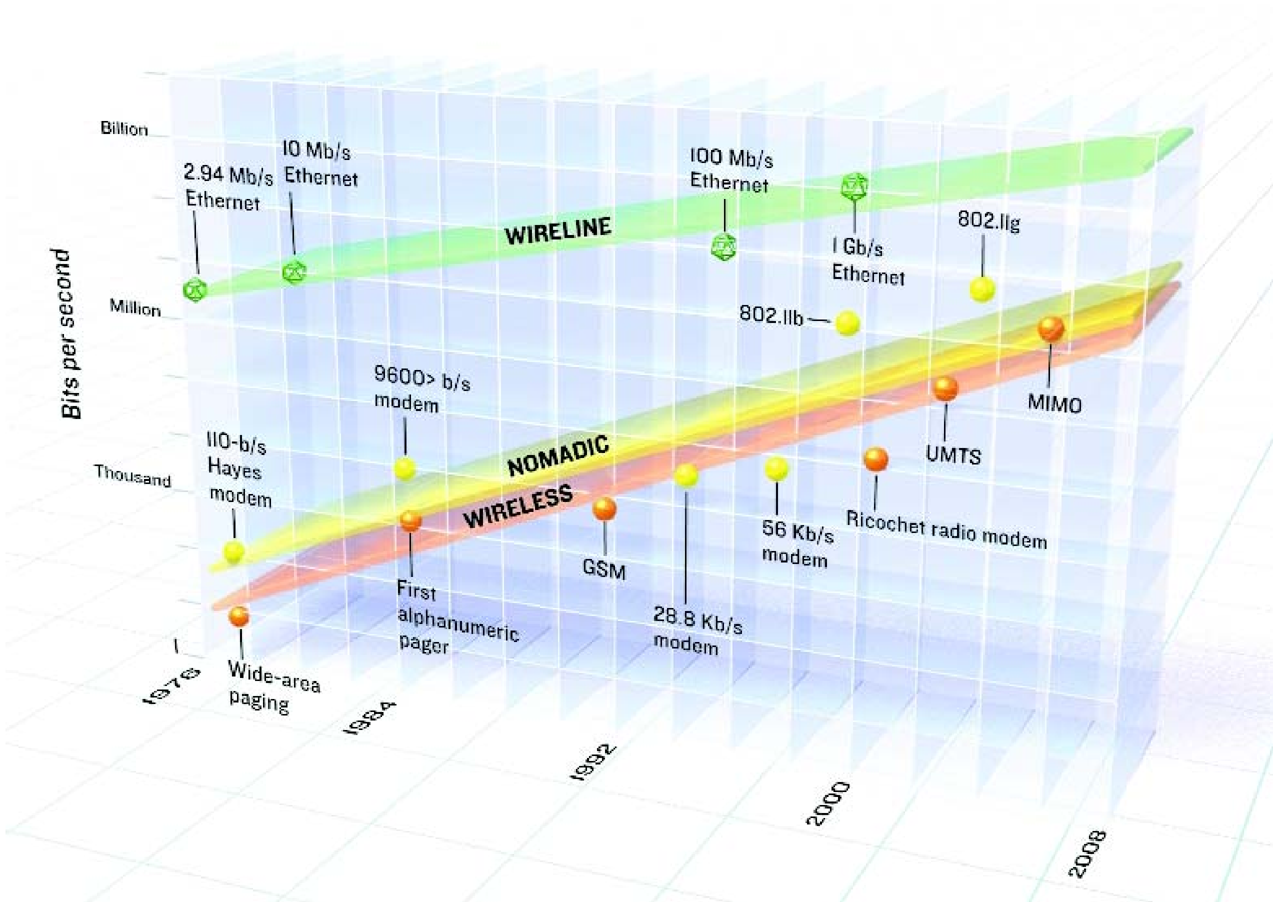

Figure 1.1 - Date rate improvements in communication technologies [1]

Currently, a growth in the numbers of subscribers, especially for data services, is already expected. This will require network operators to update and optimize their network in order to support the increasing amount of traffic and to adapt the whole network to the new communication standards and technologies. The expected growth in amount of data handled by the network is due to the enhanced performance and the new services provided by more efficient protocols in the new standards. For these reasons network planning and optimization have come into focus.

1.1 Network planning and optimization overview

Network optimization generally focuses on either of two main parameters: coverage, and capacity. Optimization of network coverage leads to an improvement in the received signal over a specific area of the network. This increases the areas over which a specific quality of service can be supported. On the other hand optimization of network capacity leads to a network that can bear a larger number of simultaneous connections or carry larger volumes of data. Several methods have been investigated to achieve these goals. Examples of such methods include: sectorization, deployment of pico cells, MIMO (Multiple Input Multiple Output) techniques, use of panel antennas and other methods. In most of the actual networks, 2-sector BSs (typical for road coverage) and 3-sector BSs (both for urban and rural area) have already been used [**3**].

Introducing 4-sector base stations or 6-sector BSs in a network systems that use a Frequency Division Multiple Access (FDMA), like the known GSM, increases the capacity of the system. It maximizes the number of connections per BS and, at the same time, minimizes the number of base stations in the network, which brings enormous cost saving [**3**].

On the other hand, a pico cell is a small coverage cell analogous to a Wi-Fi access point that can be deployed to extend coverage indoor zones where the outdoor signal does not reach acceptable level for the transmission, to increase the capacity of the network in spots with high density traffic or to simply aim the BSs in hard-to-cover areas.

The MIMO technique uses more than one antenna both in transmission and in reception improving the performance since it offers increase in data throughput without requiring more bandwidth or transmit power. In fact, it only exploits an higher spectral efficiency and link diversity.

Panel antennas are smaller than the typical antenna used in actual 3G networks and they allow an higher directivity and a tighter width of the beam, that means a more precise pointing skill.

One further technique which can be used is antenna tilting. Network improvements through tilting have previously not been considered during the planning phase, but has been used as an extra margin and to avoid excessive interference from neighboring sites [**3**]. A simple configuration of a tilted antenna is depicted in Figure 1.2.

Just by knowing a few simple parameters of the antenna (such as: antenna height, tilting angle and distances between sectors) it is possible to investigate the scenario and to optimize the network.

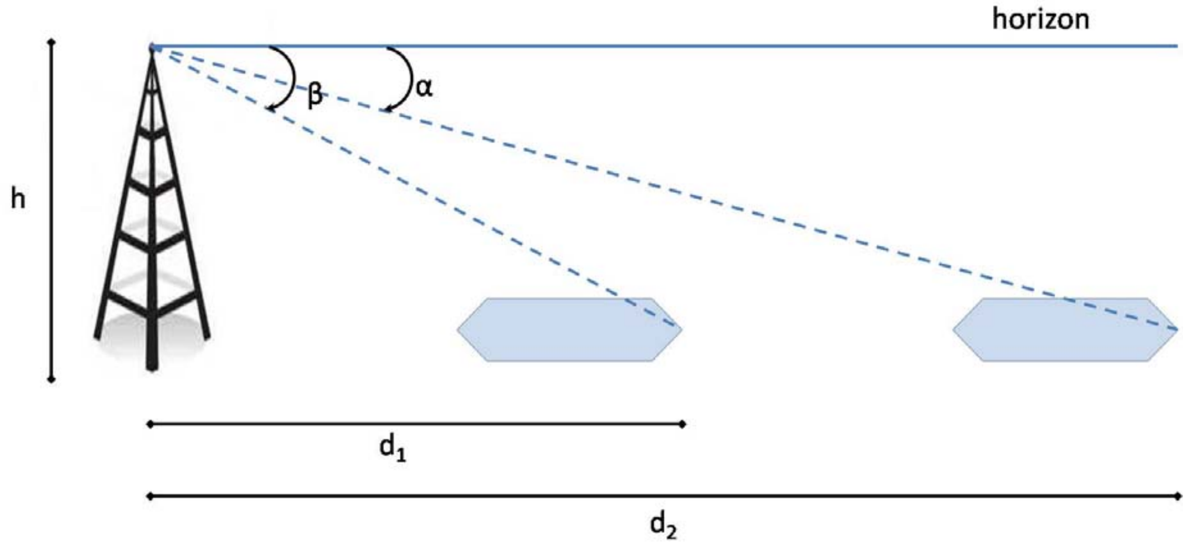

Figure 1.2 - Simple antenna tilting scheme

Sonofon, one of the largest mobile network operators in Denmark [**4**] [**5**], through a collaboration with Aalborg University and Nokia Siemens Networks, has started to analyze its own network. The idea is to optimize the current network and minimize the effects that the expected increase in network traffic will have on the network. This work will be analyzed through a static system-level simulator called SNEPATool. Different configurations will be analyzed and the configuration that shows the best result, and at the same time overcomes the performance of the actual configuration, will be implemented in the real network.

1.2 Aim of the thesis and structure of the report

Since there are no standardized procedures for finding the optimum tilting angle for each antenna within an irregular network, the main objective of this study is to propose a number of algorithms that can be used to obtain these values. Three different algorithms are presented, with each of the three algorithms having slightly different versions. The best version of each of the three algorithms is then used to consider the performance in comparison with the current existing network settings.

The algorithms have been written for and tested in the SNEPATool simulator. Therefore all of the simulations and results have been carried out using the same simulator, which is based on MATLAB®.

The report is structured as follows:

Chapter 2 gives a brief overview of the aspects of the network planning and the propagation theory that are somehow related to the antenna tilting topic. It also explainsg the difference between the two types of antenna tilting (mechanical and electrical) and tries to define the state of the art on this topic;

Chapter 3 describes the scenario used for the simulations, the structure of the simulator and the key factors adopted to analyze the results;

Chapter 4 illustrates the three proposed algorithms and their variations, showing the appropriate results and analysis for each of the different algorithm;

Chapter 5 draws the conclusions of this work and suggests some further improvements to this study.

2. Network planning and antenna tilting

This chapter introduces elements of cellular networks and aspects of propagation theory. This will be done in order to understand the problem that this work wants to face: network optimization through antenna tilting. The aspects that are relevant for network planning are examined either from a second generation or a third generation system point of view. The objective of this chapter is not to provide a full and deep understanding of the topic though, but to deal with particular issues that are necessary for understanding the work explained by this report.

2.1 Cells and handover

A cellular network is a telecommunication network that provides a connection between a number of mobile users belonging to it. It is based on the subdivision of the territory of the network in small areas called cells that are served by transceivers called base stations. The users in the network are identified by their equipments and they are called mobile stations.

The simplest way to divide the area into cells is by putting an omni-directional antenna at the centre of the cell as shown in Figure 2.1.

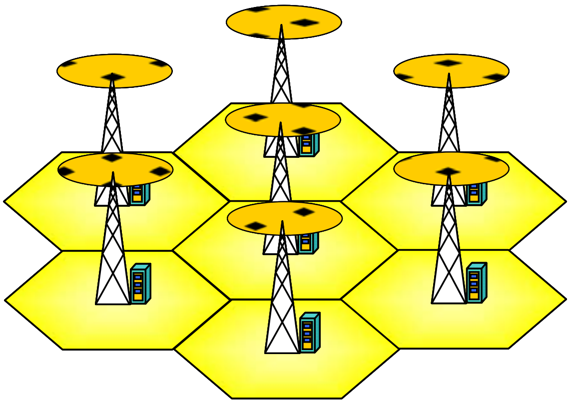

Figure 2.1 - Cell configuration with omni-directional antennas

This configuration is rarely used when planning the network. A good technique to avoid very high interferences is to deploy at the common vertex of three cells a base station with 3-sector antenna as Figure 2.2 shows.

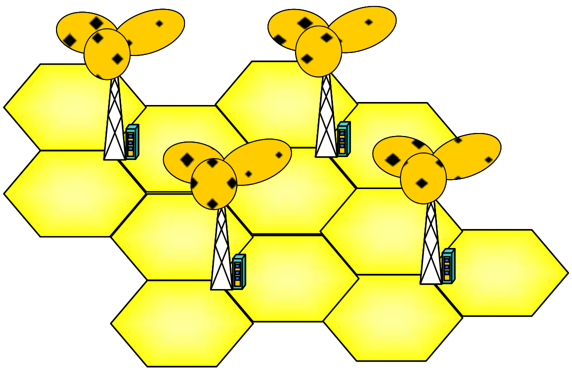

Figure 2.2 - Cell configuration with 3-sector antennas

Several type of cell can be deployed in the network and each kind has a different name depending on the size of the cell. Table 2.1 explicates the cell nomenclature and the characteristics of each type of cell.

Table 2.1 – Characteristics of different cell types

Type	Radius	Power	Antenna height
Macro cell	> 1 km	From 1 up to 20 W	> 30 m
Micro cell	< 1 km	From 0.1 up to 1 W	< 10 m
Pico cell	From 5 up to 30 m	< 0.1 W	< 2 m

In the GSM system, that uses a mixed time/frequency division multiple access (TDMA, FDMA) to the channel, each cells use different frequencies from the contiguous cells. Figure 2.3 shows two examples of a cellular division of the area using 4 and 7 different frequencies respectively. The same frequency can be reused in the network as long as the two cells using the same frequency are not adjacent to each other. The parameter that indicates how often the same frequency can be reused in the network is the frequency reuse factor. For example, in the configurations in Figure 2.3 a frequency reuse factor of 4 and 7 is used respectively.

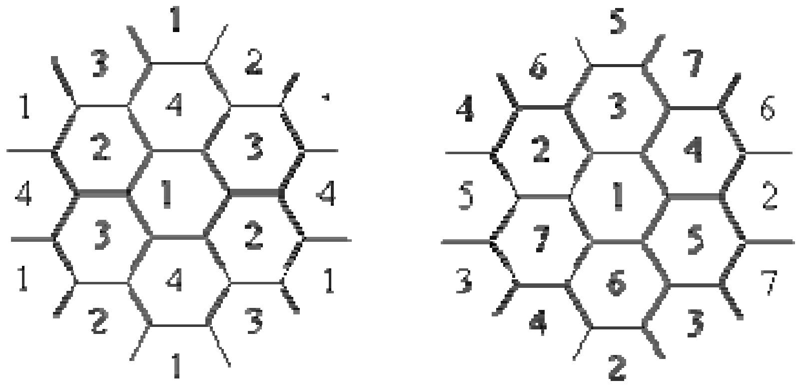

Figure 2.3 - Theoretical shape and frequency division of the cells

The higher this factor is the more different frequencies are used in the network. At the same time, a high frequency reuse factor reduces the effect of the co-channel interference. Figure 2.3 also shows the theoretical hexagonal shape of the cells, shape that does not appears in the reality because of the irregular nature of the network and the propagation effects on electromagnetic waves travelling in presence of obstacles.

Due to the topology of the network, one user that moves from one cell to another has to connect to the new frequency to be active in the network. The frequency switch is carried out through a process called handover.

In GSM, if this process has to be carried out during a call, it drops the connection to the first frequency and establishes a new one on the new cell frequency. This is also referred to ad hard handover. This is different from the handover process that takes place in UMTS, which is on the other hand called either soft or softer handover. Hard handover requires less than 400 ms to be carried out, which is a very short time for the human ear. Although it is possible to hear the *click* sound during the call when this process is done, it does not cause any particular inconveniences to the service that the operator offers to the users.

A more precise classification singles out different handover types with regard to different criteria as:

- *Homogeneity of the systems involved*: inter-system and intra-system. This distinction is used when more than one access technology to the channel take part in the process, e.g. when moving from a 2G cell to a 3G one;

- *Homogeneity of the modalities involved*: inter-mode and intra-mode. This term is used when referring to handover processes that take place between cells that are using different multiplexing methods, e.g. when moving from a TDMA to a FDMA cell;

- *Homogeneity of the frequencies involved*: inter-frequency and intra-frequency. In the UMTS system the same frequency is used all over the network hence, moving to one cell to another, even though it requires a handover process, it does not imply a change of the carrier frequency. This is called inter-frequency handover. The intra-frequency handover happens when it changes the carrier frequency moving among cells;

- *"Hardness"*: hard, soft and softer. A hard handover occurs when the old connection is dropped before establishing the new one. On the other hand, soft and softer handover need to keep alive the two connections at the same time. When one of the two channels has no longer the sufficient signal level to bear the communication then it is released. The difference between soft and softer handover is that the soft handover happens when the two cells belongs to two different eNode-B, while softer handover takes place when the two connections belongs to the same eNode-B.

The eNode-B in the UMTS systems has the same logical function that the base station executes in the second generation systems. An overview of the types of handover classifications is shown in Figure 2.4.

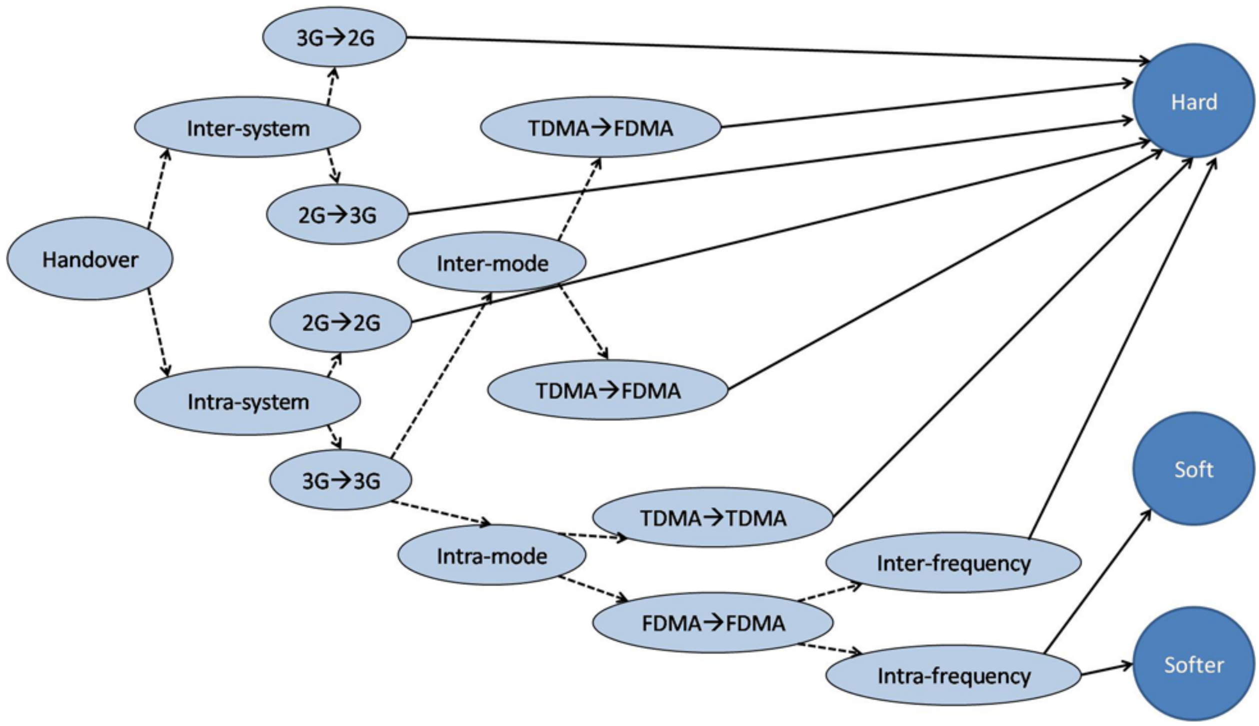

Figure 2.4 - Classification of handover types

2.1.1 Propagation related aspects

Other important issues to take into account when planning a network are:

- *Path loss*: the average measurement of the attenuation that the signal is affected by when it travels from the transmitter to the receiver and vice versa;

- *Fading*: the random phase shift of the wave, due to the signal and the medium characteristics, that affects the signal level;

- *Co-channel interference*: the interference caused by the superposition of two or more signals that came from different cells using the same frequency. This problem usually comes up when there is a low frequency reuse factor or, in other words, when the distance between cells, that use the same frequency, is too small;

- *Adjacent cell interference*: the interference due to the non ideal filters used that do not completely erase the signal outside the requested bandwidth. This factor is left out in an UMTS network planning because the third generation systems make use of the code division multiple access (CDMA) approach that allows the whole network to use the same frequencies.

These and more are the constraints to follow when planning or optimizing a mobile network. More details about the path loss, the fading and how they are implemented in the simulator are shown in the propagation section.

2.2 Propagation model of the work

The propagation theory intends to analyze the path that an electromagnetic wave follows in a medium (in this particular case air) and to study the transformations that it can undergo. In a mobile network, the main aspect to focus on is the power that the wave transports from the antenna to the receiver.

The signal loss, that appears at the receiver side, is caused by a numbers of factors. One of these is referred to as multi-path effect. This refers to the superposition of multiple versions of the same signal each of them following a different path. Each signal copy is different in signal strength, delay and phase shift while traveling from the source to the receiver. This can result in either constructive or destructive interference, amplifying or attenuating the signal power seen at the receiver.

The path a signal takes from transmitter to receiver can either be direct, reflected or diffracted. Figure 2.5 shows the difference among these three paths. Ray 1 follows a direct path to the point B because it reaches directly that point. On the other hand, rays 2 and 3 are respectively reflected and diffracted by some obstacles in the way. Both point A and B receive more versions of the same signal from the antenna. In fact, more than one ray reaches those points.

Due to multi-path, the signal propagating over a certain medium can experience, at the receiver side, an attenuation that is related either with the frequency used by the network, with the time or with the geographical position. The power density of an electromagnetic wave can be strongly reduced from one point to another. Such a reduction in power density can also be due to other factors such as the physical composition of the medium, the spatial dispersion of the wave front or the presence of obstacles between the transmitter and the receiver.

This natural loss of signal is also called path loss and it is one of the most important factors to take into account when planning a telecommunication system. Path loss normally includes number of factors that cause the reduction in signal strength.

The most important are:

- Natural expansion of the radio wave front in the free space;
- Penetration losses;
- Diffraction losses.

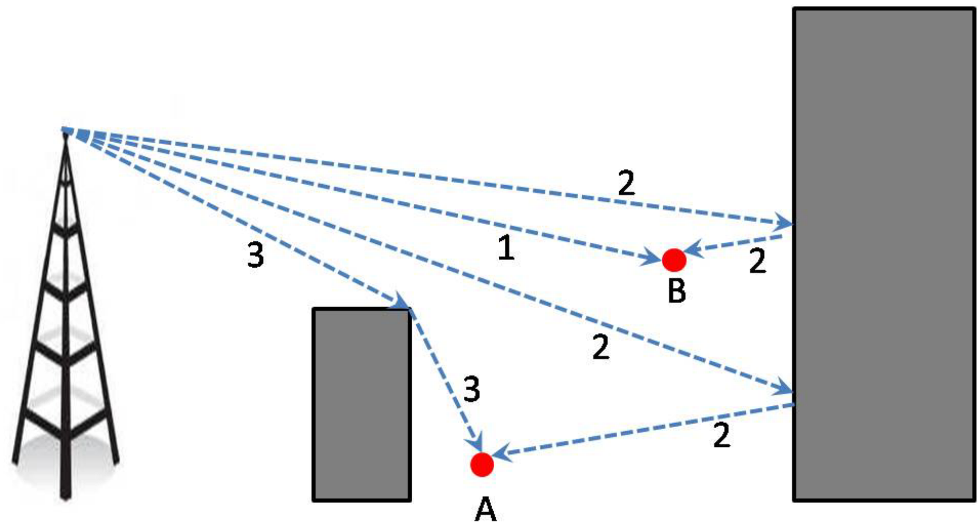

Figure 2.5 - Different kinds of the wave path

Due to the fact that a complete calculation of the path loss is very complex, it is possible only for simpler cases. In fact the path loss is usually foreseen through many approximations. For this reason, the path loss calculation is often referred to as prediction. The ways to calculate the path loss are divided into two categories: deterministic methods and statistic methods.

Deterministic methods use physic laws to calculate the path loss and they are meant to obtain more precise results. Even though they are more precise, they need a bigger computational effort and longer time when implemented in the simulator to get the results. On the other hand, although the statistic approach can provide only approximated results, it is faster in running the simulation and lighter in term of computational resources.

One of the commonest statistic method is the Okumura [**6**] model that is expressed by the equation 2.1

$$L = L_{FSL} + A_{MU} - H_{MG} - H_{BG} - G_{AREA} \qquad \text{Eq. (2.1)}$$

where,

$L =$ the median path loss;

$L_{FSL} =$ the free space loss;

A_{MU} = the median attenuation;

H_{MG} = the mobile station antenna height gain factor;

H_{BG} = the base station antenna height gain factor;

G_{AREA} = the gain factor due to the type of environment.

Okumura has developed several curves that express the median attenuation as a function of the frequency and the link distance. Moreover the Okumura method does not specify any way to calculate the free space loss. This method is used as a theoretical approach to the path loss calculation because of its idea to try to explicit the path loss as the sum of the effects of different factors each of them explicated in the equation 2.1.

A well-known method, that has been implemented in the SNEPA tool, has been suggested by Hata [**7**], who has expressed the Okumura curves in some analytical formulas. This is the reason that also explains the fame of the combined method name Okumura-Hata.

There are more than one Hata models for the calculation of the path loss depending on the type of the clutter where the model should be applied and the carrier frequencies used by the network. In the simulator two versions of this method are implemented: the Hata model for urban areas and the Hata COST [**8**] 231 model. The frequency use range is the most significant difference between the models.

The first cited model uses the formula in the equation 2.2 for carrier frequencies up to 1000 MHz

$$L = 69.55 + 26.16\log f - 13.82\log h_B - C_H + [44.9 - 6.55\log h_B]\log d \qquad \text{Eq. (2.2)}$$

with,

$$C_H = 0.8 + (1.1\log f - 0.7)h_M - 1.56\log f \qquad \text{Eq. (2.3)}$$

and the COST 231 model uses the formula in the equation 2.4 for carrier frequencies from 1500 MHz up to 1950 MHz

$$L = 46.3 + 33.9\log f - 13.82\log h_B - C_H + [44.9 - 6.55\log h_B]\log d + C \qquad \text{Eq. (2.4)}$$

with,

$$C = \begin{cases} 0\ dB, & for\ medium\ sized\ cities\ and\ suburban\ areas \\ 3\ dB, & for\ metropolitan\ areas \end{cases} \quad \text{Eq. (2.5)}$$

where,

$L =$ the path loss in urban areas;

$h_B =$ the height of the base station antenna;

$h_M =$ the height of the mobile station antenna;

$f =$ the carrier frequency;

$C_H =$ the antenna height correction factor;

$d =$ the distance between the base station and the mobile station;

$C =$ the morphology constant.

All the units of measurement are dB except for the distance d that is measured in km. Table 2.2 and Table 2.3 show the constraints that the models should be used with.

Although both Hata and COST 231 model are limited to base station antennas that have heights at least of 30 meters, they can also be used with lower antennas as far as the surrounding buildings are below the base station heights. In case the considered antennas are both below and above the rooftops another method should be used, for instance the COST-Walfish-Ikegami model [**9**].

All of these methods provide an analytic expression of the attenuation that affects the transmitted signal as a function of some variable as the frequency, the antenna heights and the distance between the actors of the communication.

Table 2.2 - Okumura model limitations

Parameter	**Granted range**
Frequency	from 150 to 1000 MHz
BS height	from 30 to 1000 m
MS height	from 1 to 10 m
Link distance	from 1 to 100 km

Table 2.3 - Hata model limitations

Parameter	Granted range
Frequency	from 1500 to 2000 MHz
BS height	from 30 to 200 m
MS height	from 1 to 10 m
Link distance	from 1 to 20 km

This function is just the result of the empirical approach to the path loss issue. Even if we could measure the path loss which the wave is affected by, we could just find out that the values are fluctuating all over the empirical expression. These variations can be ascribed to the fading. In fact the loss that affects an electromagnetic wave can be dived in macroscopic path loss, shadow fading and fast fading. Figure 2.6 shows a simplified graph which depicts the difference between the effects of the macroscopic path loss and the sum of both path loss and shadow fading effects.

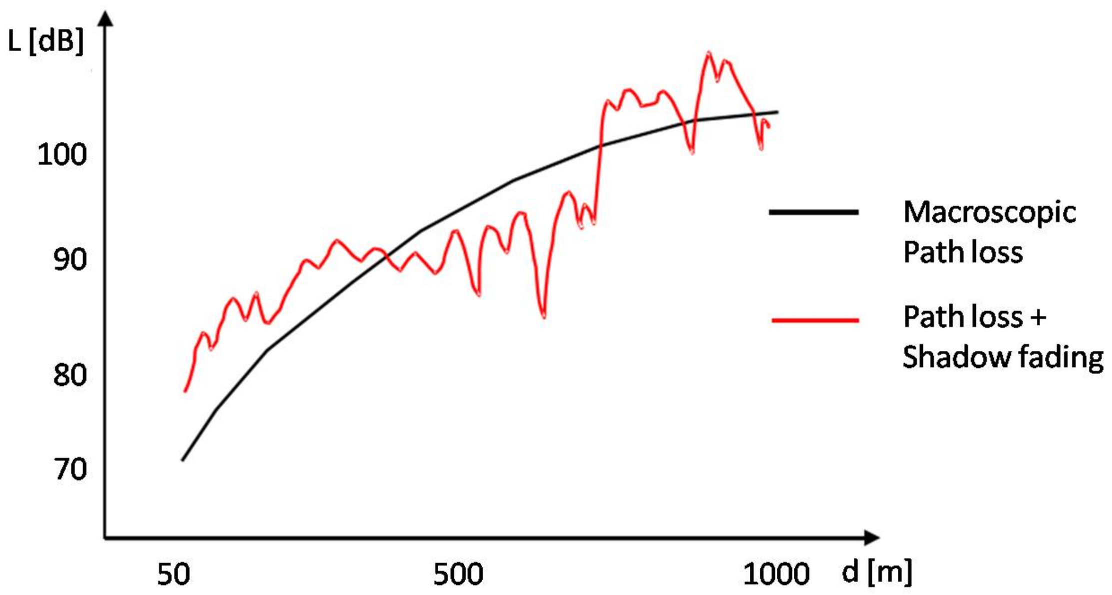

Figure 2.6 - Typical path loss trends

Fading is a random process that can be divided into two categories: slow fading and fast fading. Slow fading, also referred as shadow fading, is part of the over-the-air path loss and manifests itself in the variations of the measured signal strength [**9**]. These variations of the signal mean amplitude are log-normally distributed and thus this phenomenon is also called log-normal fading. The shadow fading is caused, as the name suggests, by the presence of large and stationary obstacles that cause reflections and diffractions in the path. For considering the effects related to the shadow fading, the shadowing map of the network is generated in the SNEPA tool. Therefore a log-normal distributed error margin is taken into account.

The second type of fading is called fast because it causes rapid changes of the signal level and it is due to the multipath effect at the receiver antenna side. Figure 2.7 adds a brief part of the fast fading curve to the curves shown by Figure 2.6 and compares all of the three factors that compose the path loss focusing on the different speed of variation of each one.

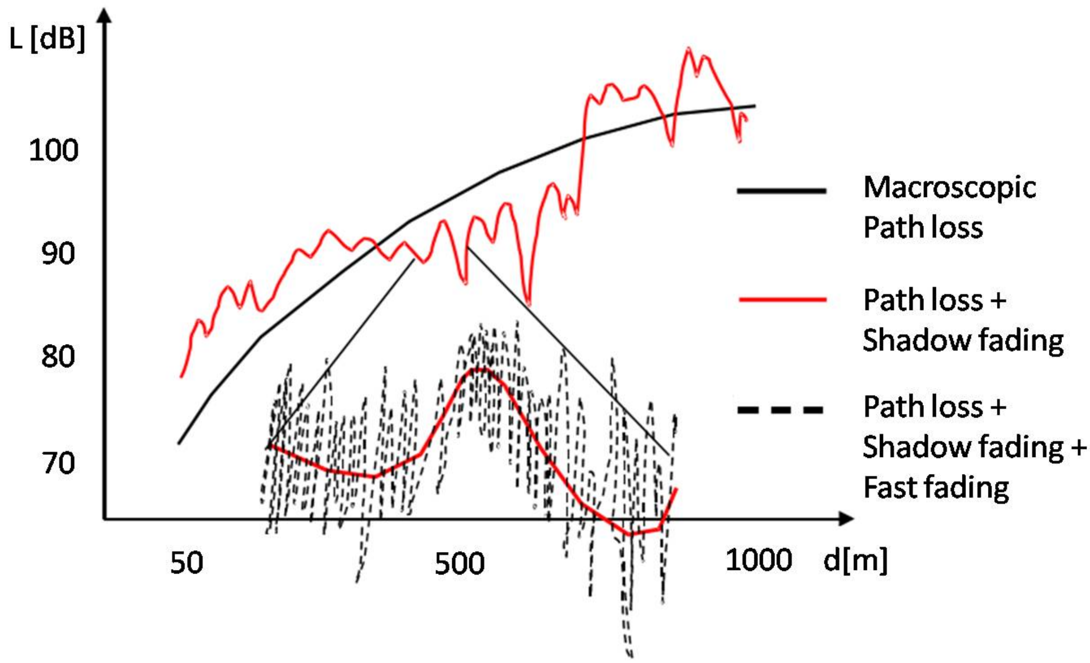

Figure 2.7 - Typical path loss, slow fading and fast fading trends

2.3 Tilting

Tilting technique effects the radio pattern of the antenna. Therefore it is important to fix, on its characteristic, some datum points and references which refer to in order to clearly understand how to exploit this technique.

Every antenna owns a radiation pattern that is three-dimensional. For simplicity reasons it can be divide in two projections on a vertical plane perpendicular to the horizon, and on the horizontal plane. The first one is named vertical radiation pattern, the second is the horizontal radiation pattern. In the horizontal plane the radiation pattern gives a hint of the cell coverage as Figure 2.8 shows.

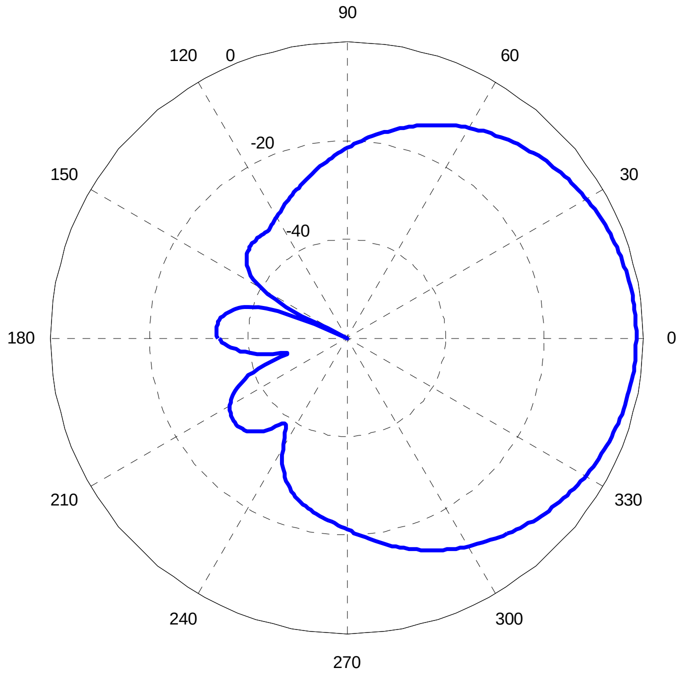

Figure 2.8 - Horizontal radiation pattern

Concerning the vertical radiation pattern, that is the most used for developing this work, some important characteristic properties have to be considered. Figure 2.9 shows part of an antenna vertical radiation pattern in polar coordinates while Figure 2.10 depicts a zoomed version of the same radiation pattern but in Cartesian coordinates.

The highlighted blue part of the pattern is referred to as main lobe because it indicates the part of the antenna characteristic that carries most of the part of the signal power. The red arrow indicates the direction of the main bean which in this case (a no-tilted antenna) coincides with the horizontal direction.

The black arrow depicts the direction of the first notch. The first notch indicates, starting from the highest value in the graph, the first minimum of the radiation function which is, for the antennas used in the network investigated by this work, about 6° far from the main beam direction.

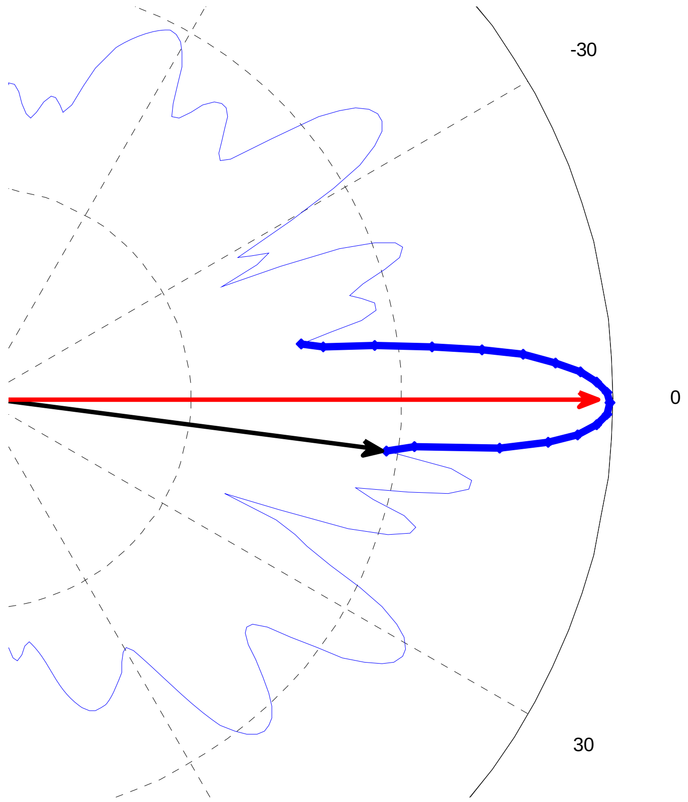

Figure 2.9 - Part of a radiation pattern in polar coordinates

Figure 2.10 highlights the first notch with a black circle. The green arrow in the same picture is the direction that links the antenna to the -3dB point of the main lobe in the radiation pattern. This point, for the antenna of the studied network, is about 3° far from the main beam direction. These two directions (first notch and -3dB) have been used for the algorithms proposed by this work.

In a wireless network planning or optimization phase, tilting the antennas is a way to face several kinds of problem such as the coverage holes and the co-channel interference. It is as well the simplest way to operate on the wave propagation on both the vertical and the horizontal plane.

On the other hand, a too high value of tilting angle can be damaging for the use of soft and softer handover. In fact, these procedures require, at the same time and in the same place, two channels which the user equipment should be connected to. This means that a common overlapping area in the edge zone of two adjacent cells is needed and desirable. At the same time, this common zone cannot be too wide otherwise the co-channel interference would be above the maximum level for having a good connection. The point is to find the best compromise.

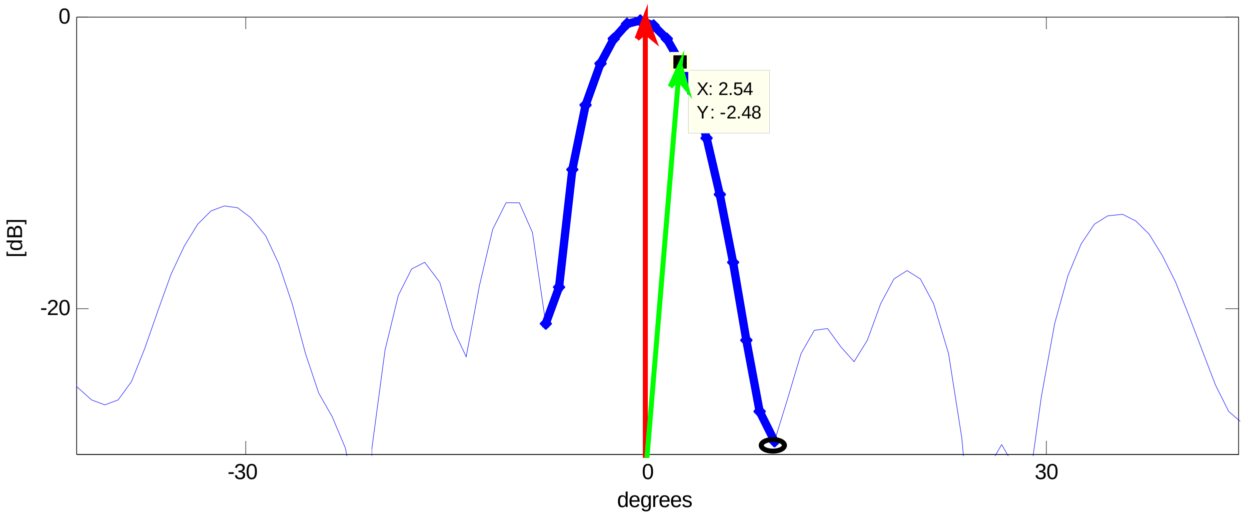

Figure 2.10 - Part of a radiation pattern in Cartesian coordinates

Other two factors to work on when planning and/or optimizing the network are e.g. the azimuth angle of the antennas and the transmitted pilot channel power with other common channel powers. About this last option, it consists in assuring that these channel are received with sufficient quality by all users in the serving cell. At the same time a minimization of the common channel powers yields significant capacity gains: first, additional power becomes available for other (user traffic) channel, and secondly, the interference is reduced.

It is important to note that in a capacity limited UMTS network (e.g. urban areas) the reduction of pilot power levels by a factor of Δ also reduces the total transmit power of cells and as a consequence the cell loading by up to the same factor Δ. About the optimization of the azimuth angle of the antenna, it is observed that changes on it are in particular introduced in order to reduce coverage problems [**10**].

Among these three parameters for optimizing an UMTS network, studies [**10**] show that the most effective parameter for network optimization is antenna tilting.

Figure 2.11 [**10**] depicts the percentage of the missed traffic per reason in an large Asian urban network consisting of more than 900 cells. The results come out from different optimization scenarios and they show that the largest improvements are reached by using the tilting technique.

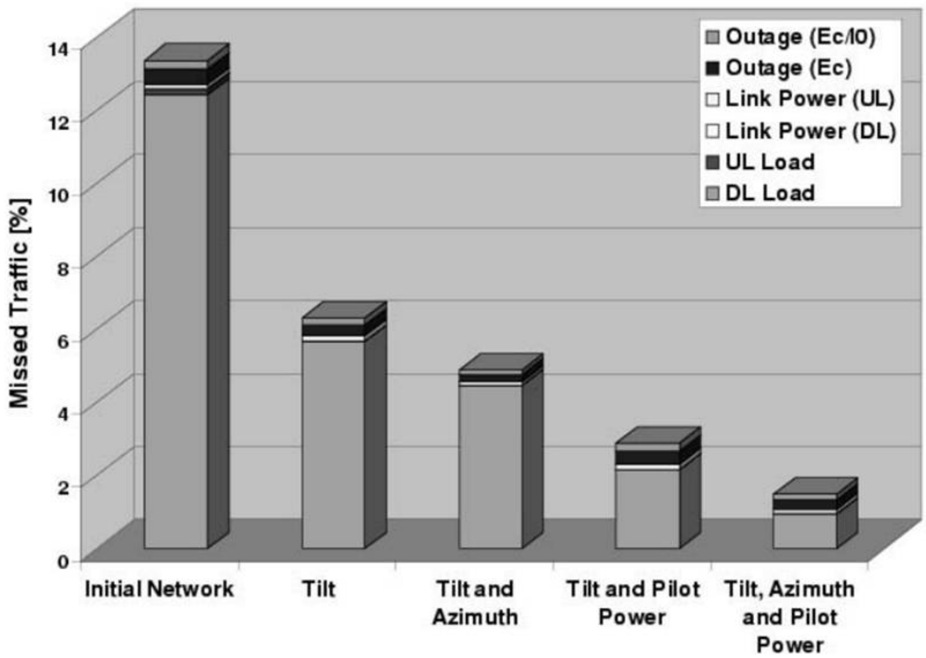

Figure 2.11 - Missed traffic per reason for different optimization scenarios [10]

Figure 2.12 [**10**] explicates, in terms of percentage of overloaded cells, that the best improvements are reached by tilting antennas. About the 50% of the improvements is achieved by employing only the tilt angles optimization.

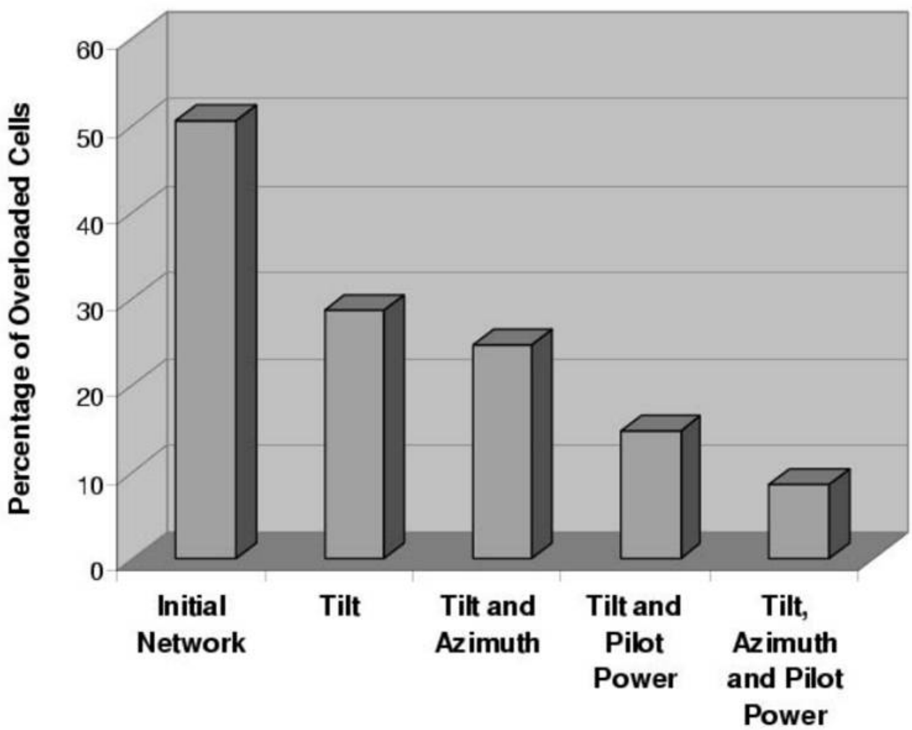

Figure 2.12 - Percentage of overloaded cells for different optimization scenarios [10]

Further studies [**11**] demonstrate that the path loss deduced from the COST 231 Hata model decreases when the tilting angle increases. The increasing is continuous from a value of 3° to 10°. Figure 2.13 [**11**] depicts the path loss at the cell boundary for different values of the tilting angle as a function of the antenna height.

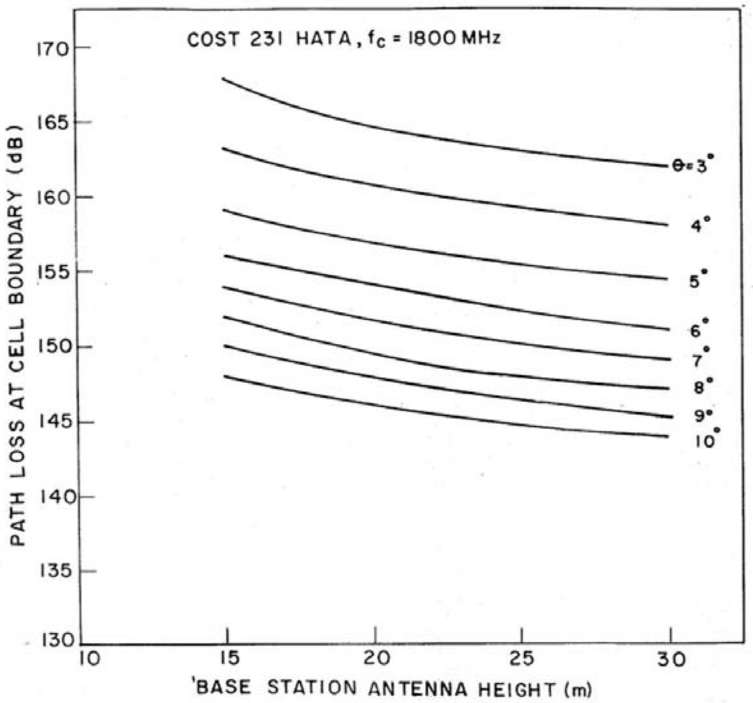

Figure 2.13 - Path loss at cell boundary deduced from COST 231 Hata model as a function of BS antenna height [11]

2.3.1 Mechanical and electrical tilting

There are two different mechanisms for adjust the tilt angle of an antenna: mechanical and electrical tilting. Figure 2.14 [**12**] shows an example of a simple antenna tilted with an angle of α degrees by using both the mechanical and the electrical technique. The first method physically tilt the whole antenna. Therefore from the point of view of the network operator, this technique means a very slow procedure with further costs involved. The electrical tilt can be performed from remote by using the central control unit of the antenna. Further technical information on a common antenna from of the the leader in the antenna production can be found in [**13**].

The tilt angle value, which can be reached through either of both techniques, is the same but the resulting antenna radiation pattern is different. In fact, when using the mechanical tilting the antenna radiation pattern is not affected by the change but it is just oriented differently. On the contrary, when using the electrical technique, the antenna radiation pattern is slightly different from the original because the distance of the separate antenna elements to each other changes depending on the value of the angle α [**10**]. Mechanical down-tilting shrinks the main lobe coverage area but not the side lobe coverage areas. Electrical down-tilting shrinks the coverage area uniformly in all directions. Therefore, in order to reduce the inter-cell interference, electrical tilted antennas are preferred for urban area deployment [**9**].

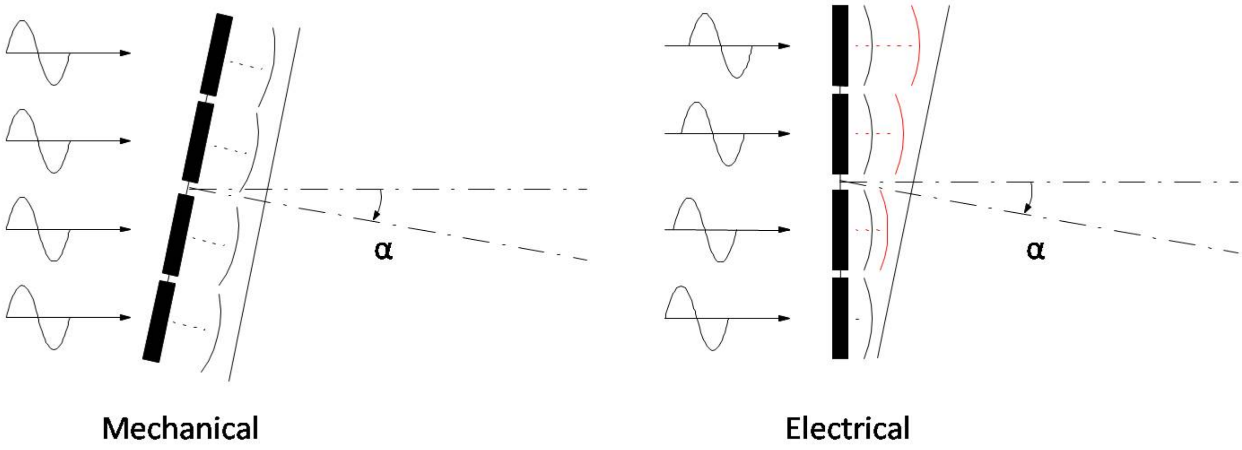

Figure 2.14 - Mechanical and electrical down-tilt [12**]**

Figure 2.16 shows the changes that affects the cell coverage in case the antenna is tilted mechanically or electrically. The light grey zone indicates, in both mechanical and electrical case, the main and the back lobe of the antenna without being tilted and the related covered area. On the other hand, the dark grey zone shows the different orientations of the antenna main and back lobes either when it is mechanically tilted or when the electrical tilting is used. The covered area in both cases changes but not in the same way for both the tilting techniques. In fact also the back lobe undergoes different modifications depending on the way the antenna is tilted.

Polar diagrams of the radiation pattern of a random antenna in the network studied for the present work are shown in Figure 2.15 and Figure 2.17.

Figure 2.15 shows the radiation pattern of the antenna without being tilted and with a mechanical tilt angle of 6°. The radiation pattern is the same for both the tilting angle values assumed. The only difference is that, when the antenna is tilted, the radiation pattern is tilted as well, but it does not show any change.

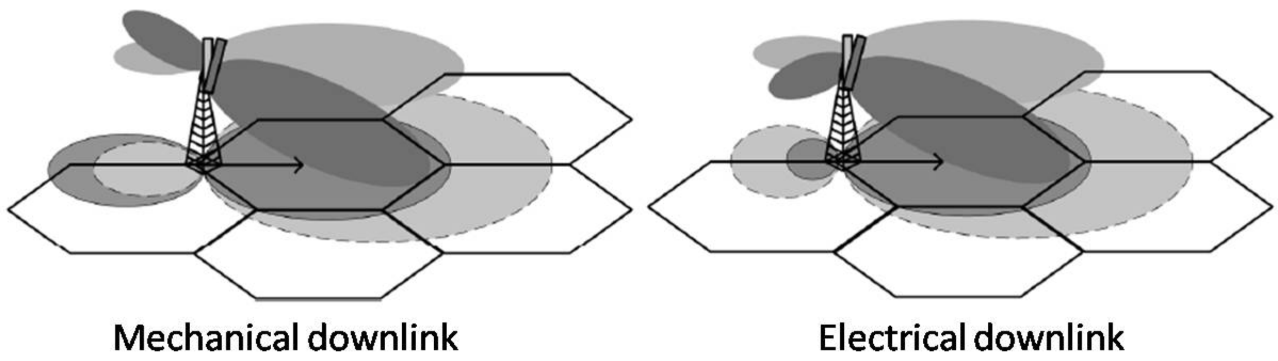

Figure 2.16 - Coverage changes in mechanical and electrical tilting

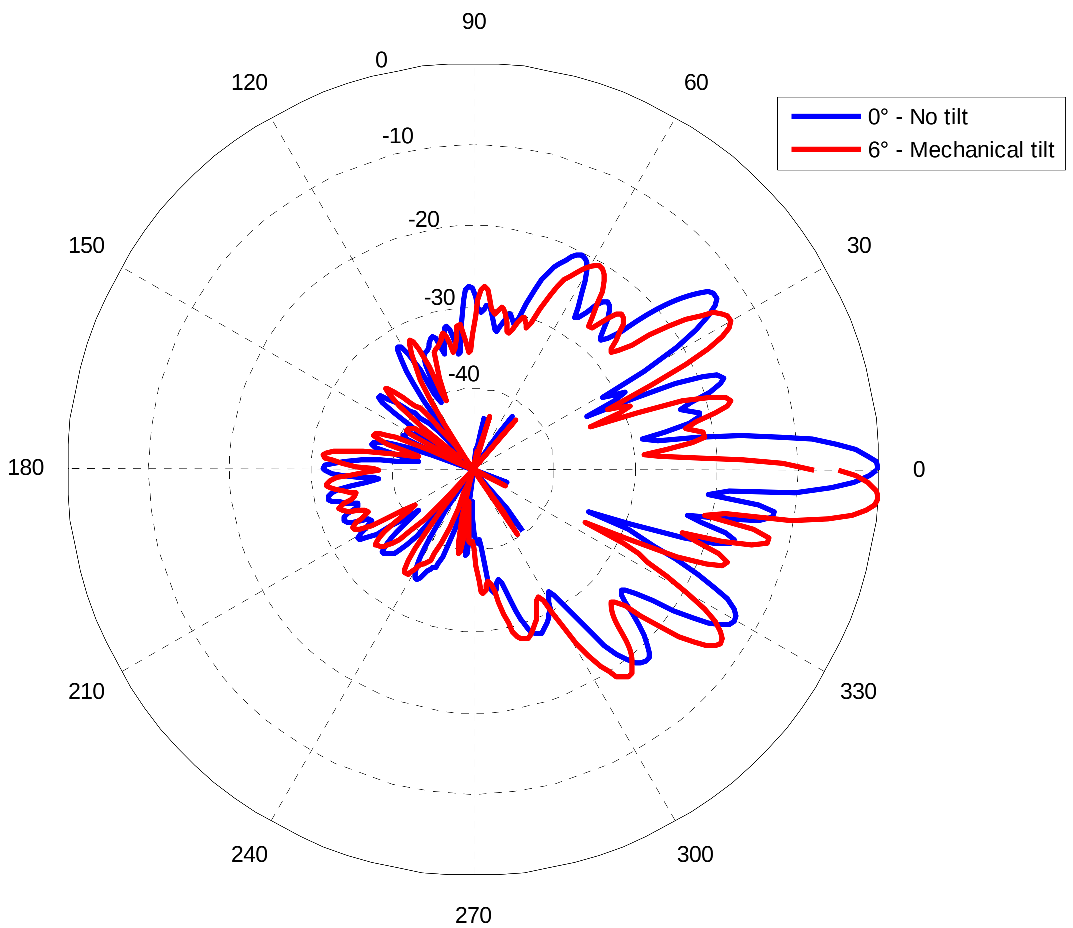

Figure 2.15 - Mechanically tilted antenna radiation pattern

Figure 2.17 depicts the radiation pattern of the same antenna without being tilted and again with a 6° tilt angle achieved by using the electrical tilting though. In this case the electrically tilted radiation pattern is not only rotated. It is possible to find out several and evident changes in the shape of the characteristic of the antenna due to the fact that the electrical structure of the antenna is changed when using the electrical tilting.

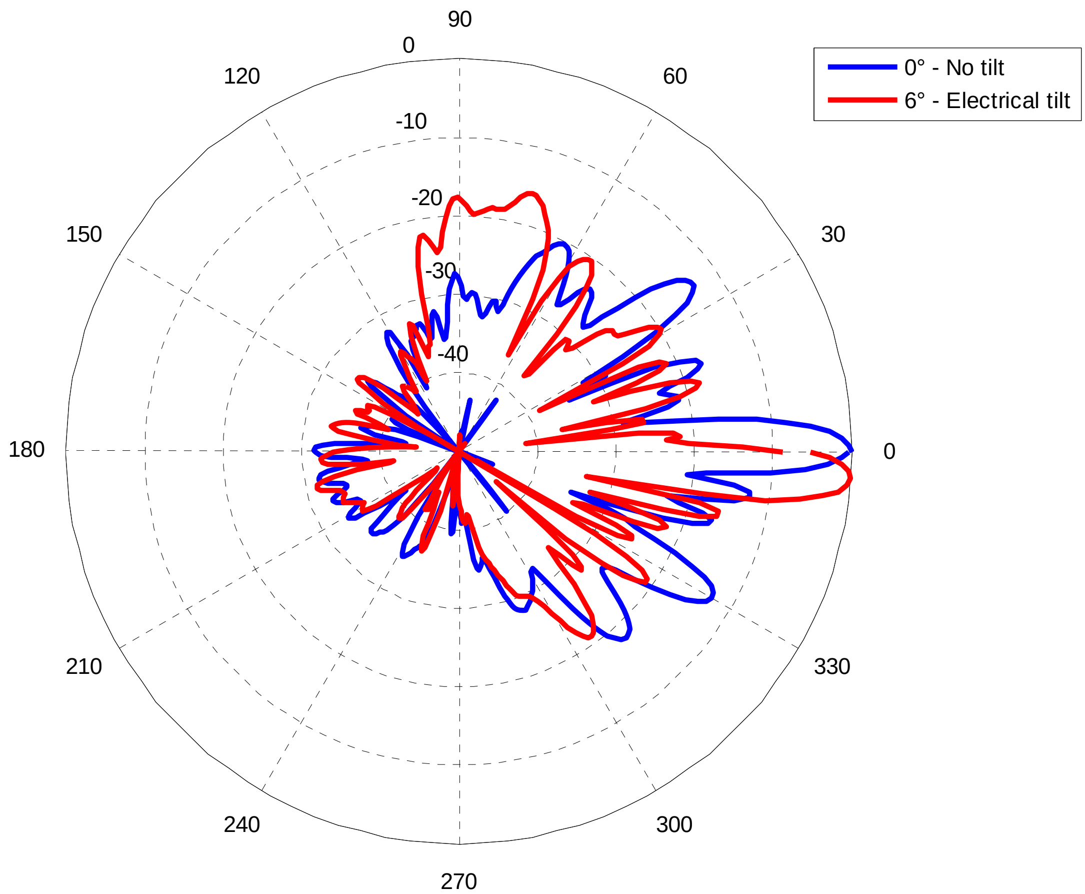

Figure 2.17 - Electrically tilted antenna radiation pattern

3. Project description

This chapter describes the network scenario used for the simulations and explains the structure of the simulation tool used for testing the different tilting optimization algorithms, SNEPATool (System and Network PlAnning Tool).

3.1 Introduction to the project

The work presented in this report is part of a larger project which Sonofon, Aalborg University and Nokia Siemens Networks are currently engaged in. Such a project is intended to provide Sonofon with feedback on possible network improvements and the effects that these can have on the network's coverage and capacity. On the other hand, the network operator has to first supply network related information that can be imported within SNEPATool and used for the various investigations.

In particular the goals of the whole project can be summed up as being:

- Investigation on the performance of the current single carrier 3-sector configuration;
- Investigation on the possible methods for enhancing the current network configuration: antenna tilt, dual carrier and 6-sector;
- Investigation on the performance and costs of introducing pico sites;

The work presented in this report only focuses on the effects of antenna tilting. A number of algorithms have been investigated for obtaining optimized tilting angles.

3.2 Scenario description

The study area of the project includes just a small area of the Sonofon network in the center of Copenhagen. This means that every analysis of the project is focused on this area and all the changes that are suggested by the results will be applied only in this area for the first period to test the new configuration. If the modifications will pass the test period then the new configuration will be kept and the study can be then extend to a larger area.

Figure 3.1 - Aerial view of the Copenhagen area object of study

Figure 3.1 shows an aerial view of Copenhagen taken from [**14**]. This picture also includes the area of Sonofon's network that is being investigated. Sonofon provides all of the available information about the 3G sites within the green circle. While all sites are imported and used within the simulation tool, some of them are excluded from the results in order to avoid wrong results related to the border zone. This effect at the border is due to the incomplete calculation of the interferences in the border area since the base stations placed in a zone that is just slightly outside the circumference, are not taken into account. The green area has a radius of about 2.5 km.

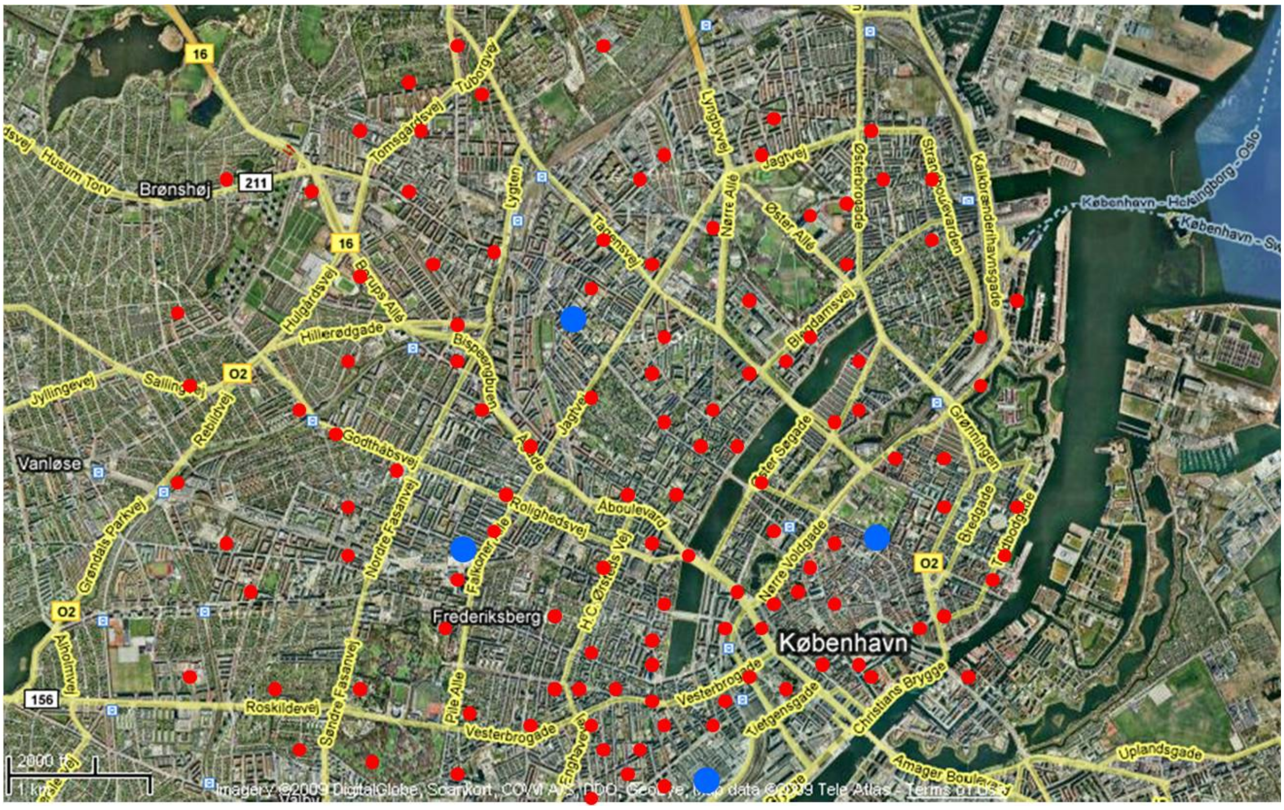

Figure 3.2 - Study area base station deployment

Figure 3.2 shows the location of the existing 3G sites within the area being investigated. The blue dots indicates omni-directional antennas while the red points represent 2-sector or 3-sector antennas in the network.

This area is composed by around 125 base station sites. Most of the sites are 3-sector sites apart from a few 2-sector sites and four omni-directional antenna sites. This means that the project takes into account more than 300 cells. In most of the cases, second and third generation sites are co-located. However, for this particular case only third generation sites are being considered. This decision is supported by the fact that all of the new technologies and network improvements are related to the 3G network, its protocols and their evolutions.

For making a first easier approach to the problem, the analysis is limited to the downlink channel. Moreover, the study only concentrates on the data transmitted by using HSPA (High Speed Packet Access). This can be divided into: HSUPA (High Speed Uplink Packet Access) only used for the uplink channel, and HSDPA (High Speed Downlink Packet Access) that is used for the downlink communications. In other words only the traffic generated by the HSDPA protocol will take part in the simulation. This protocol theoretically introduces enhancements in transfer rate (in downlink), and in general over the whole transmission, by applying such techniques as:

- *AMC (Adaptive Modulation and Coding)*: this technique enables the base station to switch among modulation schemes and coding on a user basis, according with the channel conditions or, more precisely, with the signal quality and cell usage. The initial modulation scheme is the QPSK (Quadrature Phase Shift Keying) which handles data rates up to 1.8 Mbit/s. In the best conditions the used modulation scheme is the 16-QAM (Quadrature Amplitude Modulation) which allows data rates up to 3.6 Mbit/s. The theoretic limit of 14.4 Mbit/s can be reached by using codes;

- *Fast packet scheduling*: this feature enables a channel-depending packet scheduling. In fact, every active user equipment periodically sends information to the BS about the channel conditions. This transmission is carried out 500 time per second. By using the information of all the users, the base station decides the best users for being sent the data and the amount of data for each user for the next 2 ms. The better the user quality feedback is, the highest the amount of data the base station can send to is;

- *HARQ (Hybrid Automatic Repeat reQuest)*: by sending data to the users multiple times using different code, a sort of incremental redundancy is achieved by this feature. Then, if the received packet is corrupted the user keeps the packet and compares it with the retransmitted packet which contains the same information but encrypted with a different code. Even if the retransmitted packet is also corrupted, the right combination of the two corrupted packets can give the original correct one avoiding a further retransmission.

3.3 SNEPATool simulator

The SNEPATool simulator is a MATLAB®-based software developed in Aalborg University with the collaboration of the Nokia Siemens Networks.

Figure 3.3 depicts the SNEPATool software flowchart showing the state of the development of each block (at this moment) by using the color legend on the left side of the figure. The green color is used for indicating blocks already complete or almost done. The yellow "on-going" is used for the blocks that are available for the simulator but are still object of study or needing a further optimization. The light-blue blocks are not in use. The blocks relative to the down tilt adjustment and its optimization criteria have been developed for carrying out the present work.

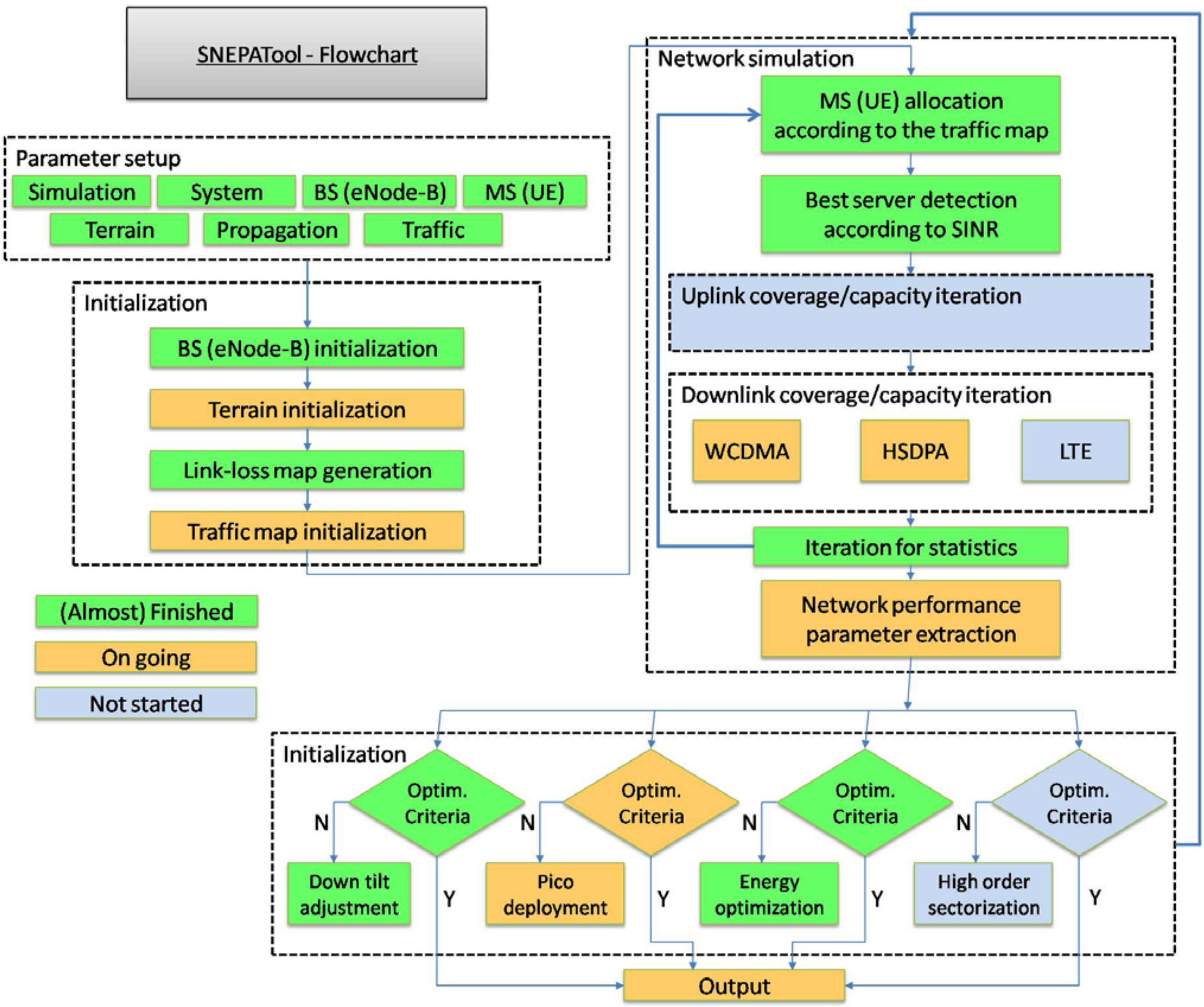

Figure 3.3 - SNEPATool flowchart

This block structure of the simulator enables its users to quickly find and identify the various sections putting the simulator together, allowing for necessary modification to be made. Its modular design also allows for foreign users to develop and integrate their own blocks within the simulator, by extracting and returning the correct parameters.

Following the scheme in Figure 3.3, the simulator starts loading the simulation parameters such as information about the base station, the mobile users, traffic distribution and so on. By using this information it starts to calculate the link loss between each user to each base station. This is followed by the generation of a traffic density map, which is based on real data extracted from the network. For the present work, a uniform traffic distribution has been chosen. A lognormal traffic distribution will be available in the next phase of the project for generating more irregular traffic with a number of hotspots.

After this step the network simulator starts by dropping users in the area, according to the chosen traffic distribution, and generating the best downlink server area map and the coverage map.

Figure 3.4 - Example of a best server area map

Figure 3.4 shows an example of a best server area map obtained by the Sonofon simulator. This map indicates, by using different colors, which zone is being serving by which antenna. Such a map is the fundamental starting point for the tilting methods proposed by this report. The resolution used in the simulations presented by this work is 50 meters.

Figure 3.5 is an example of a coverage map extracted from the network planning tool used by Sonofon. It indicates the SINR level in the area of interest. The green areas are the ones which are subject of the highest SINR level in the map. In decreasing order of SINR, the other levels are: yellow, orange, red and blue, where the SINR level is the 'worst' in the map.

The SINR and the DLTP (Down Link ThroughPut) are the selected key factors for analyzing simulations results. No images for the DLTP have been provided by Sonofon.

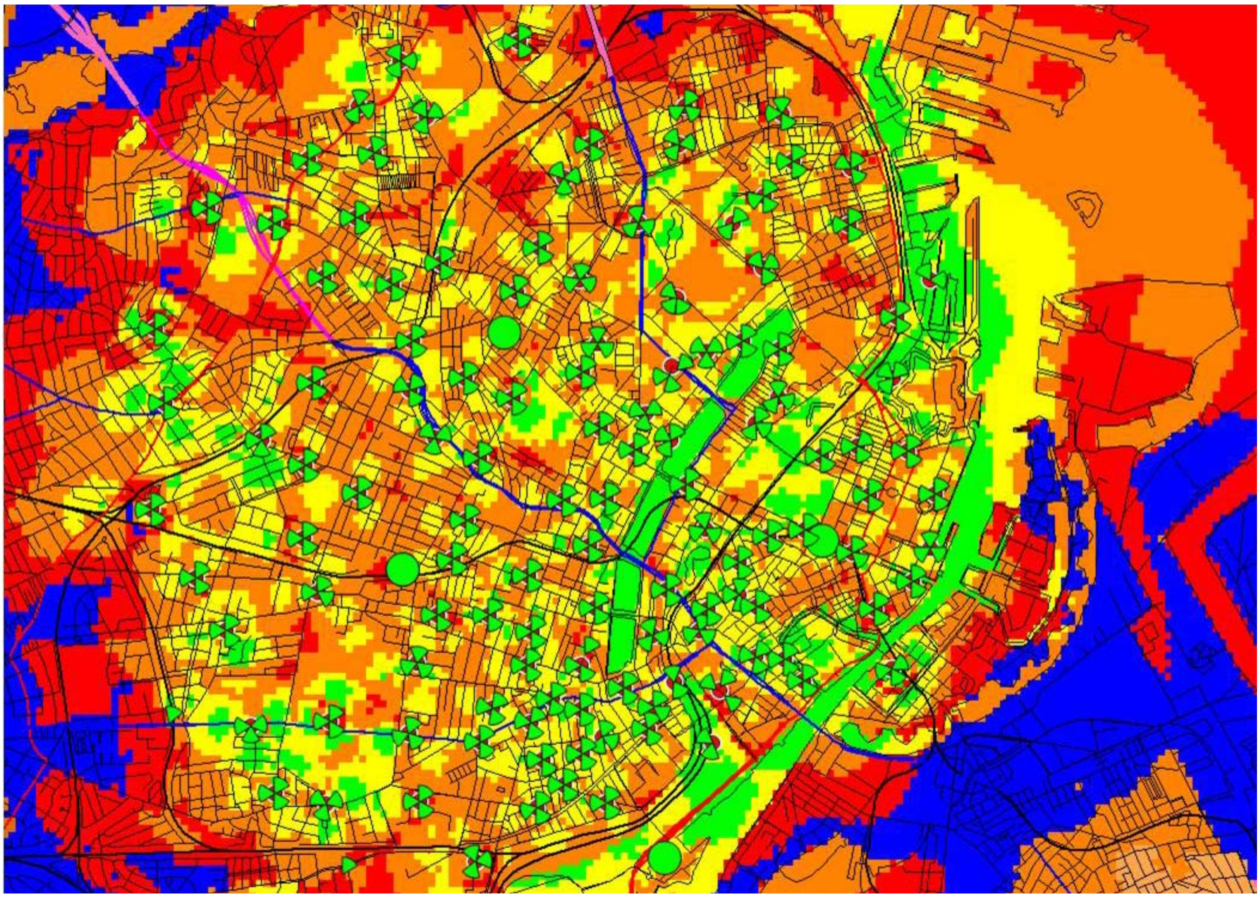

Figure 3.5 - Example of a coverage map

After generating these maps, the simulator repeats this process several times and saves all the results. This ensures that the results obtained from the simulator are actually based on statistics and not on a single individual instance. From these results the network performance parameters are extracted. In the case of having any type of network optimization being carried out, these parameters are used as an input. Examples of such network optimization includes: energy saving, pico cells deployment and down tilting of the antenna. After each optimization, the simulator starts over and recalculates the new coverage maps with the new updated parameters. This loop continues until each of the optimization criterion, used by each block, fulfills the requirements. For network optimization through tilting, only a single iteration is required. This is because the proposed methods find the intended values of the angle geometrically, just by using the first generated best server map. Then the tilting values, which can be the result of any suggested method, is kept for the whole simulation.

At the end of the simulation the final coverage map, best server map and downlink throughput map are showed. Besides, a graph of the CDF (Cumulative Distribution Function) of the SINR and of the DLTP in the study area is also provided. The results related to the methods investigated by this work are presented by analyzing these two graphs generated by each simulation.

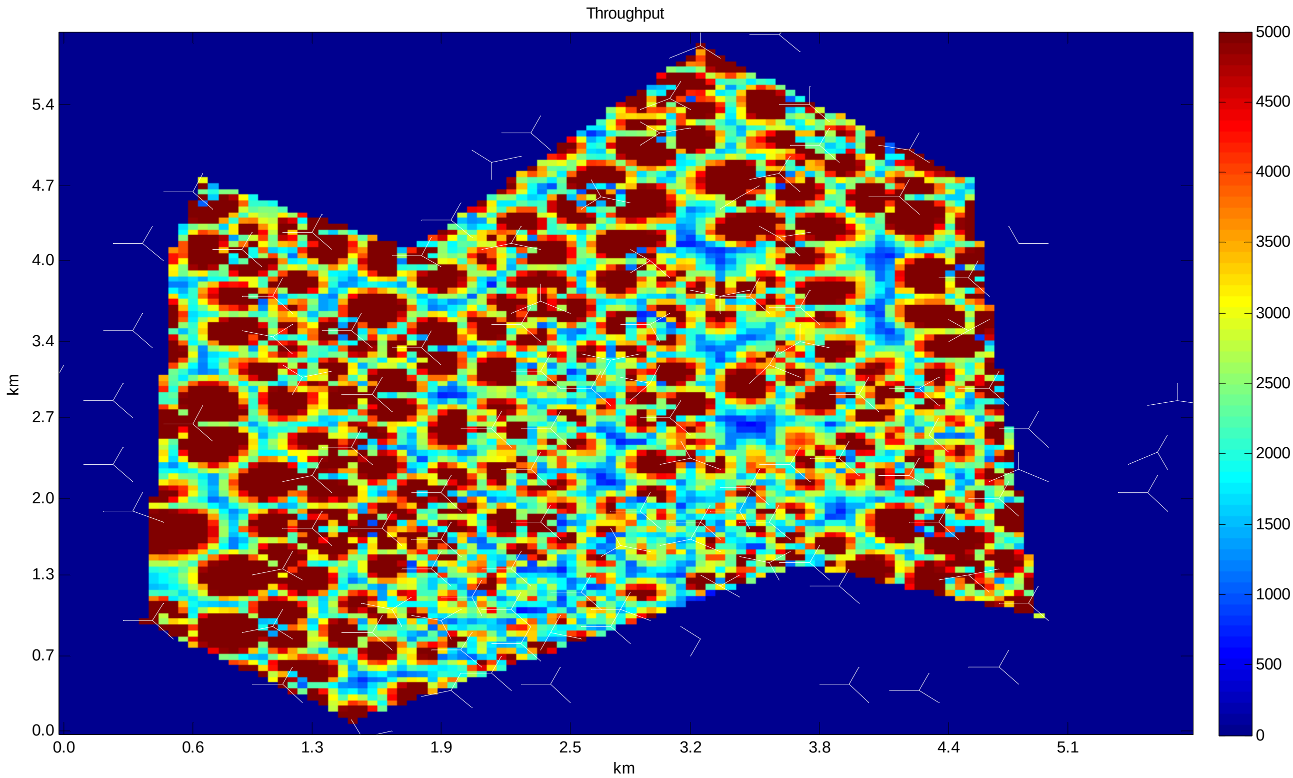

Figure 3.6 - Example of a down link throughput map

Figure 3.6 shows a random simulated DLTP map. The delimitated irregular area is the area where the results are calculated without being affected by the border effect, the effect due to the fact that the base station beyond the initial circle are not considered. The legend in Figure 3.6 is expressed in kbps.

3.4 Key factors

As said before, the selected key factors for analyzing the results are the SINR and the downlink throughput. More precisely, the cumulative distribution function of these two parameters of the overall study area is investigated by this report. Therefore, a little deepening on these aspects is presented in this section.

The SINR, as its name says, is the ratio of the transmitted signal power to the sum of the noise power and the interference power. Noise usually is considered every factor, internal to the system, which disturbs the communication by overlapping the desirable signal. Typical example of noise is the thermal noise. By the term interference it is considered every external signal that degrades the desirable signal. Thus, the interference comes from other equipments which transmit their information to their relative receivers. These signals can reach also receivers which are not interested in those information causing disturbs with the desirable signal.

Therefore, the SINR is defined either by equation 3.1 o in dB by equation 3.2,

$$SINR = \frac{P_S}{P_n + P_I} \qquad \text{Eq. (3.1)}$$

$$SINR(dB) = 10\log\frac{P_S}{P_n + P_I} \qquad \text{Eq. (3.2)}$$

where,

$P_S =$ the power of the desirable signal;

$P_n =$ the mean noise power;

$P_I =$ the power of the interfering signals.

The higher the ratio is, the better the quality of the received signal is.

On the other hand, the downlink throughput indicates the average data rate of the information transmitted by using the downlink channel. In other words, it considers the actual data rate of the channel taking only into account the amount of data that actually reaches the receiver. This parameter gives the idea of the average data rate of the channel from the user point of view. In fact, although the amount of data travelling through the channel is higher considering e.g. the retransmissions and the communication control packets, the DLTP factor is the closest idea that a final user can have about the data rate of the channel since only successful packets are taken into account.

The simulator calculates the SINR through approximations and statistical methods and DLTP by a mapping curve SINR to DLTP. For this reason these two factors can be handled as random variables. Therefore, the graphs provided by the simulator show the cumulative distribution function of both these parameters.

Given a random variable X, its cumulative distribution function $F(x)$ can be mathematically expressed by equation 3.3,

$$F(x) = P(X \leq x) \qquad \text{Eq. (3.3)}$$

where,

X = the random variable;

x = a real number;

$F(x)$ = the cumulative distribution function of X;

$P(X \leq x)$ = the probability that the variable X is equal or less than the real number x.

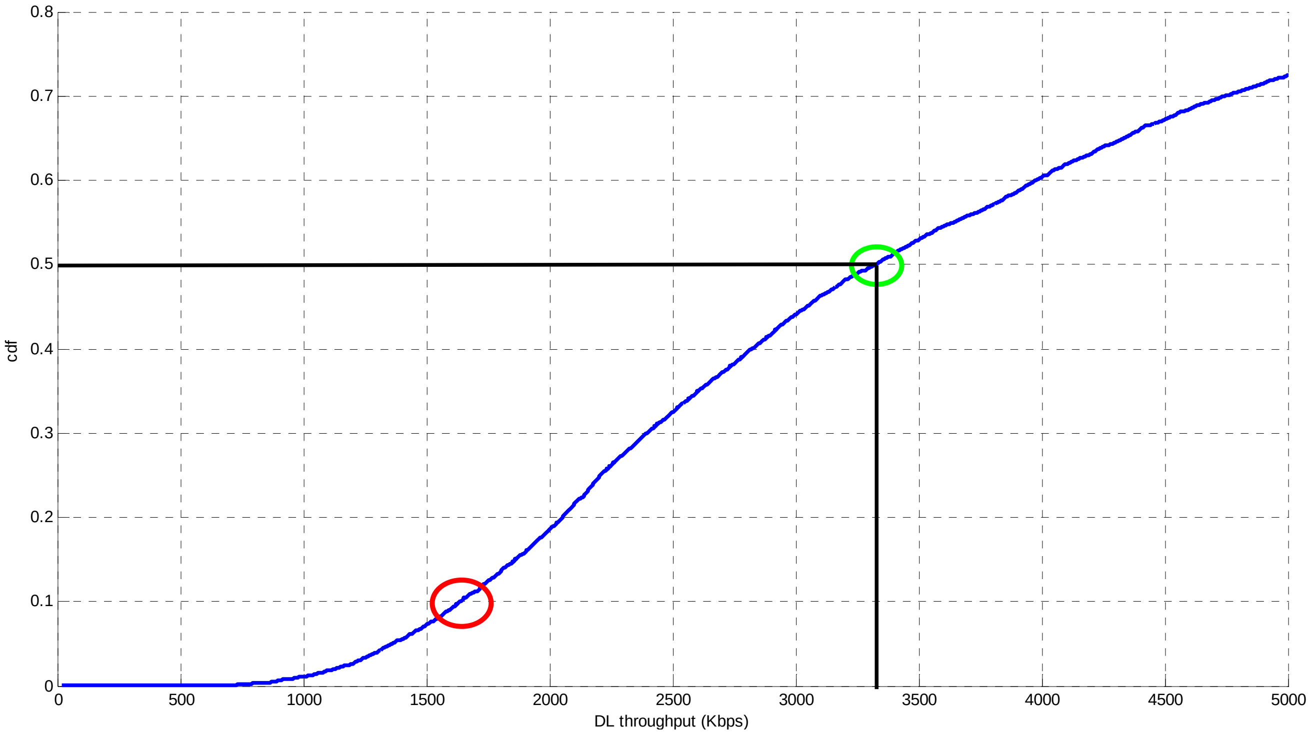

Figure 3.7 - Example of the cumulative distribution function of the DLTP

With reference to Figure 3.7, which shows the cumulative distribution function of the throughput for a simulated random network, particular values of the distribution are highlighted. The green circle indicates the throughput value corresponding to a value of 0.5 of the cumulative distribution function. This throughput value can be assumed as the average throughput value of the network. Other critic values are the values corresponding to low levels of the throughput. The red circle indicates the throughput value that the network will perform with a 10% probability. Once the required probability is fixed by the project specification, it is possible to easily know, by using this graph, the value of the throughput that the network guarantees with the required probability. The same critic values and the same reasoning can be done referring the cumulative distribution function of the SINR.

It's important to note that when two curves are compared each other on the graph, as shown in Figure 3.8, the one on the right side is the one whose configuration shows the best performance. In fact, Figure 3.8 shows that the configuration represented by the red curve has an average SINR of about -3dB whereas the blue one represents a configuration with an average downlink SINR of about 2dB. Same reasoning can be done with any critic value of the cumulative distribution function. Further in this work, a threshold in the lowest part of the graph is chosen. This threshold usually is equal to 5% of the distribution and it defines a limit below which comparing the two curves is not relevant. This part of the graph, which presents low values of the analyzed parameter (either SINR or DLTP), is the one which most of the attention is focused on. This is because that is the part related to the areas which show the worst performance of the network. Therefore, that is the part which most needs enhancement. This reasoning is an example of how to quickly verify the results shown by this report.

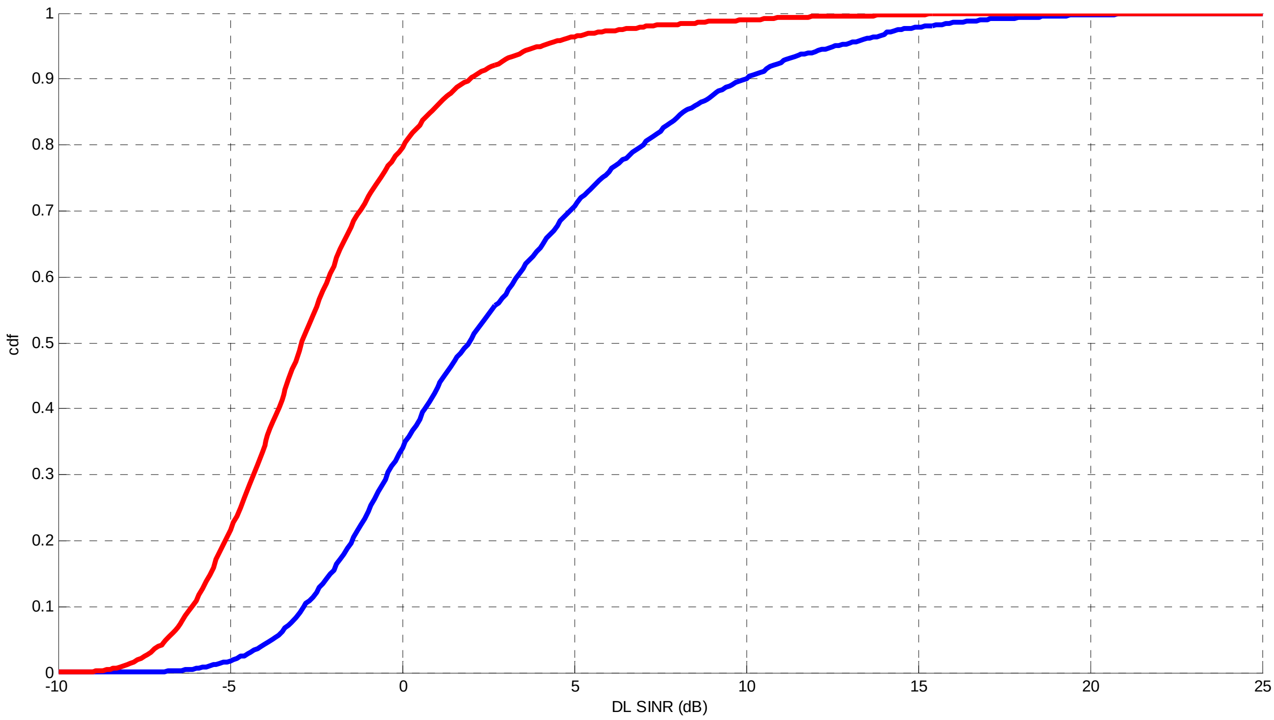

Figure 3.8 - Example of comparison between two curves

4. Implementation and results

This chapter describes the proposed methods for optimizing the tilting angle of the antennas in a mobile network. The first two methods focus their attention on the point where the main beam of each antenna reaches the ground. On the other hand, the third algorithm focuses on the point where either the first notch direction or the -3dB power direction of each antenna touches the ground.

4.1. Introduction to the proposed methods for tilting

Ideally, any optimization algorithm has to be easy to implement and fast during execution. Even though such algorithms have their own limitations, this is the approach used as a starting point for the work presented in this report.

The optimization process is considered structured in two smaller tasks. The purpose of the first task is to obtain a first ‘sub-optimal’ solution, which is then passed to next optimization stage. Figure 4.1 shows a simplified model of the whole optimization process. Finding a first acceptable solution through a simple and fast algorithm is the target of the pre-process. This first solution should give a good and acceptable idea of the tilting angles that should be used in the network. However, these angles could possibly be improved further through a more complex tuning process. In Figure 4.1 this further process is referred to as ‘final optimization’.

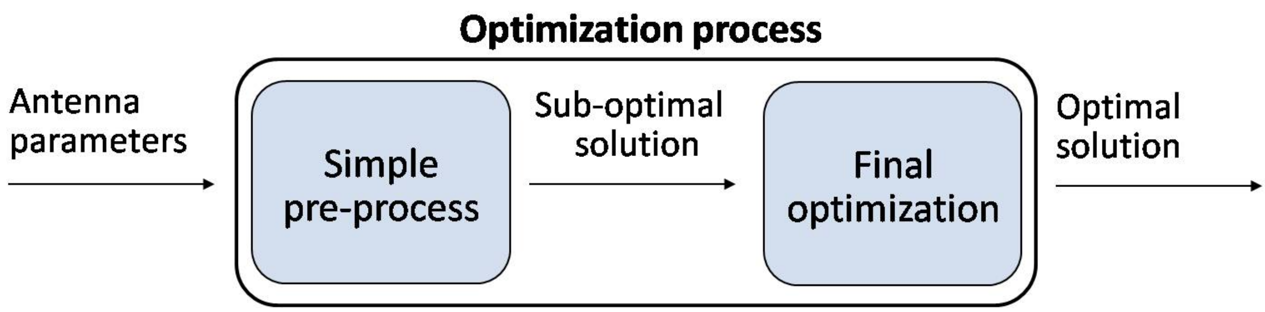

Figure 4.1 - Simple general optimization model

All of the proposed methods use a simple two dimensional approach to keep the complexity of the process low. In this work three methods are described. All of them calculate a point where either the main beam or some other characteristic part of the radiation pattern has to hit the ground.

Through a number of approximations, that can be easily updated and improved, the algorithm is kept simple and fast. First of all, the height of the ground is not taken into account. In the scenario being considered, the ground is assumed to be entirely flat. Even though the algorithms do not take this information into account for the results presented in this report, they can be easily modified to include the ground height information when such information is available.

In the presence of such information, Figure 4.2 shows how the algorithms would convert this information and represent it as a single height value. Beside this, a clutter map is also being excluded from the investigated scenario. This means that the entire area is considered as being uniform (single clutter type), which does not take into account additional propagation losses due to heights of the buildings, trees, etc.

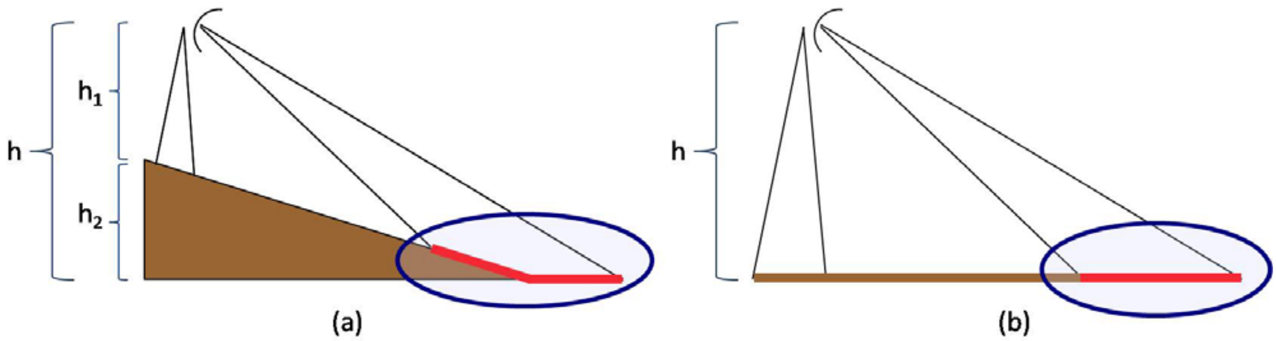

Figure 4.2 - Heights approximation scheme

All of the methods have been tested first on a regular network as Figure 4.3 shows. In the Figure 4.3 the crosses indicate the position of the antennas, while the little circles indicate the furthermost point in each sector. In this specific case, these points (indicated by circles) are used further in this work by one of the proposed methods. In this scenario only 3-

sectors sites are considered, therefore each site is in fact represented by three superimposed crosses, one for each antenna.

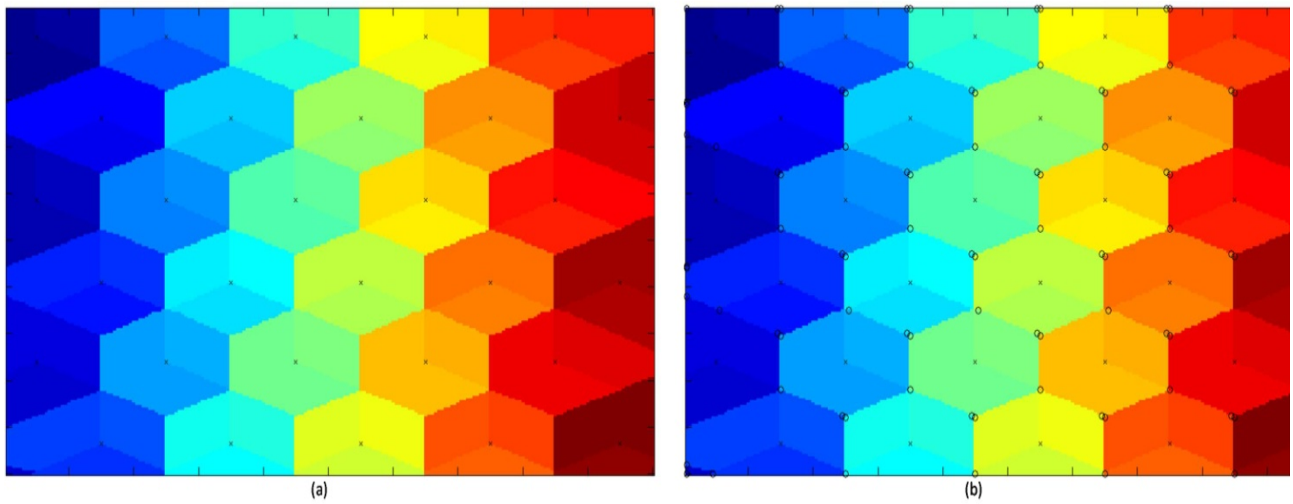

Figure 4.3 - Furthermost point method on a regular network

Figure 4.4 shows the same process applied to the real network scenario (case study) that is used for this work. In Figure 4.4 (b) it might be difficult to make a clear distinction between different sectors due to the fact that a similar color has been used in neighboring sectors.

It is important to note that neither of the presented algorithms has an effect on the azimuth (horizontal) angle of the antennas.

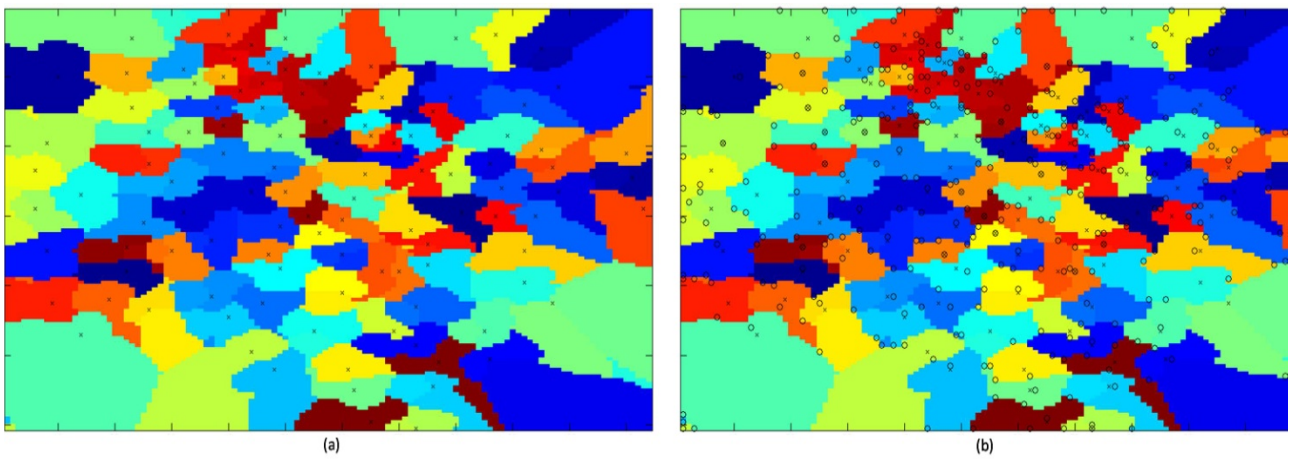

Figure 4.4 - Furthermost point method in the real network

4.1.1.Furthermost point method

The logic behind this method is to maximize the level of received power at the cell edge. This algorithm points the main beam of the antenna pattern towards the ground at a point that has a distance, from the node B, equal to the distance between the antenna and the furthermost point within that same sector. For the sector size, the first best server map generated by the simulator is used. A simplified scheme is shown in Figure 4.5. In this way a considerable part of the main lobe power goes outside the sector, overlapping with neighboring sectors. This overlapping ensures a suitable area over which either a soft or a softer handover procedure can be carried out. However, this also increases the interference with the adjacent sectors. Therefore, for finding the best trade off, three variations of this method are proposed.

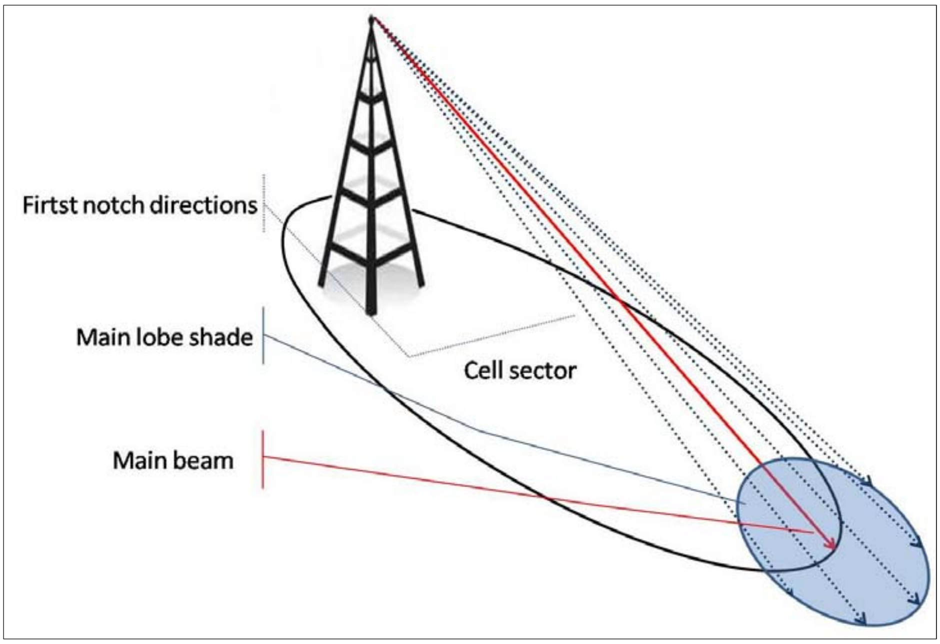

Figure 4.5 - Furthermost point scheme

The variation involves that the distance between the antenna and the point of interest, i.e. where the main beam should point towards, is made shorter and shorter (closer to the antenna) since most of the main bean power goes outside the sector. This distance in the initial algorithm is the distance between the antenna and the furthermost point in the sector. The three variations to this method take a point that has distance 10%, 30% and 50% shorter. For this reason, the three methods are referred to as ‘Furthermost point -10%’ or ‘FM -10%’, ‘Furthermost point -30%’ or ‘FM -30%’ and ‘Furthermost point -50%’ or ‘FM -50%’ respectively. In all cases, the algorithm starts by finding the furthermost point within each sector. Then, for each of the presented variations, the correct distance (based on the distance reduction percentile) is calculated. Once this is done, the algorithm calculates the required tilting angle for each antenna in order to point the main beam toward that point by using only geometric assumptions.

4.1.2.Largest Common Border method

The main idea of this method is again to direct the main beam towards a specific point. One specific point could be considered *interesting* e.g. due to low level of received power or because it is affected by an high level of adjacent interference. In this case the middle of the largest common border between two neighboring sectors is chosen as the point of interest. The reason behind this choice is that this area is expected to be the one that is mostly affected by adjacent sector interference.

This method starts by trying to couple the various sectors together (based on which of the other sector shares the longest boarder). Figure 4.6 shows an example of how this coupling process is carried out. In the example in Figure 4.6 sector 3a is effected by sectors (served by different antennas) 1b, 1c and 2b. Due to the length of the border the algorithm couples the sector 3a with the sector 1b (they share the largest border). The largest common borders are highlighted with two red lines in Figure 4.6. Sector 2b and sector 1c are respectively coupled with sector 3c and sector 2a following the previous reasoning.

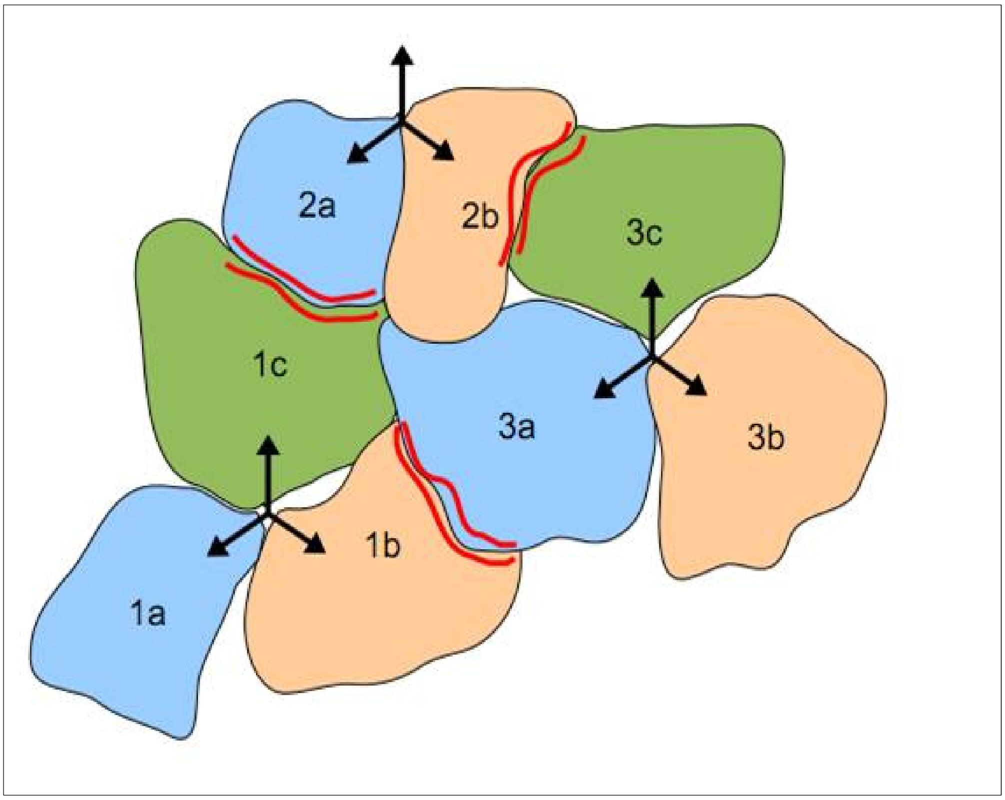

Figure 4.6 - Example of a sectors configuration

Once the largest common border method completes this work for the whole network the algorithm finds the middle point of the common border for each pair of sectors. This task is followed by calculating the distance between each antenna and this middle point on its common border. The main antenna beam is then pointed (through tilting) towards a point that has a distance equal to the calculated value. The idea is explained in Figure 4.7.

It is important to remind that neither this algorithm nor the others modify the azimuth angle (direction) of the antenna. Therefore every antenna points towards the same direction as before, with the only parameter that changes being the tilting angle.

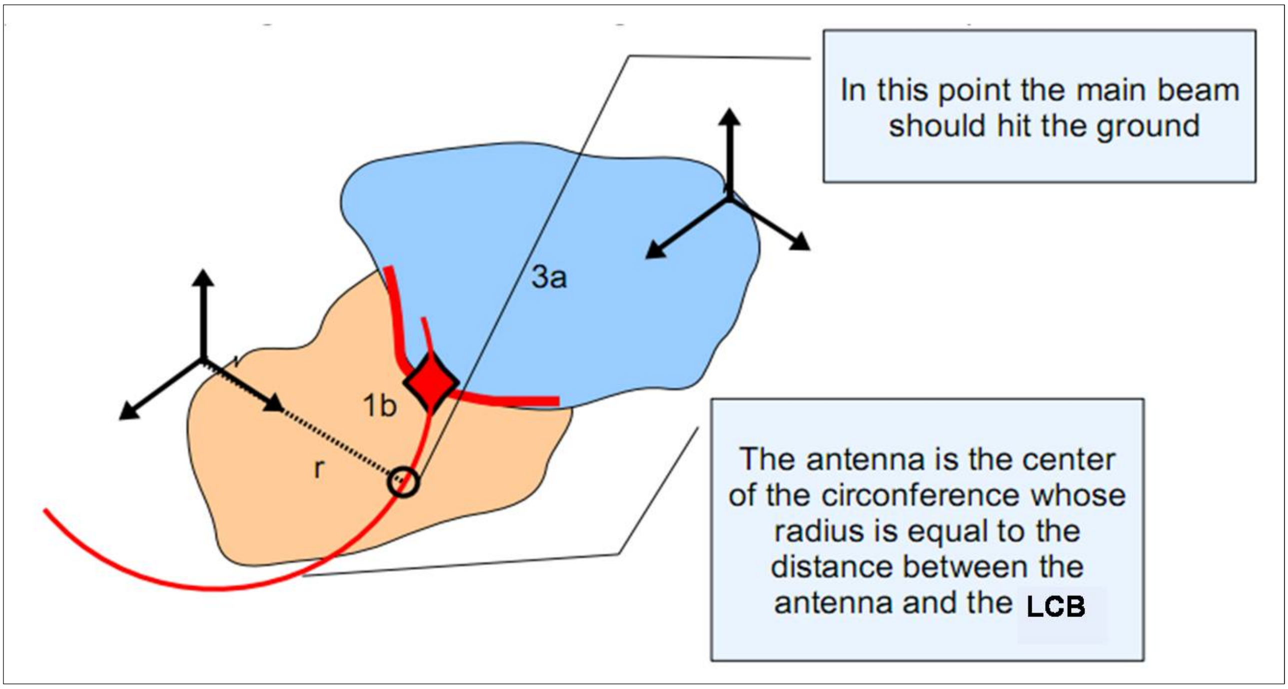

Figure 4.7 - Largest common border method

Often, when using this method, the main beam is noted to be concentrated close by the antenna instead of spreading it towards the cell edge. For this reason, a number of variations to this algorithm have also been implemented. In this case the modifications to this algorithm increases the distance between the antenna and the point towards which the main antenna beam is pointed at. Similar to previous method, the three variations increase the distance by 10%, 30% and 50% respectively. Therefore the methods are respectively referred to as 'Largest common border +10%' or 'LCB +10%', 'Largest common border +30%' or 'LCB +30%' and 'Largest common border +50%' or 'LCM +50%'.

4.1.3. First Notch method

This method combines the geometry of the sector with the knowledge of the antenna pattern. The goal is to use the antenna diagram in order to exploit its own vertical pattern characteristics for improving the signal quality within the sector.

The algorithm matches the direction of the first notch of the antenna with the cell edge. The case is well explained by Figure 4.8 which shows how the beam corresponding to the direction of the first notch hits the ground at the border of the cell. In fact the blue area in Figure 4.8 represents the zone where the main lobe reaches the ground. The main beam, indicated by a red arrow, is inside the cell and the direction of the first notch matches the sector border. Therefore all the power related to the main lobe is kept inside the cell. In Figure 4.9 the vertical pattern of an antenna used in the study case is shown. As the diagram shows, the direction of the first notch for the antennas in the study area is on average 6 degrees away from the direction of the main beam. In order to distinguish between several methods every reference to this algorithm will indicate the amount of degrees with a number between brackets. Therefore this method is referred to as 'First notch (6°)' or 'FN (6°)'.

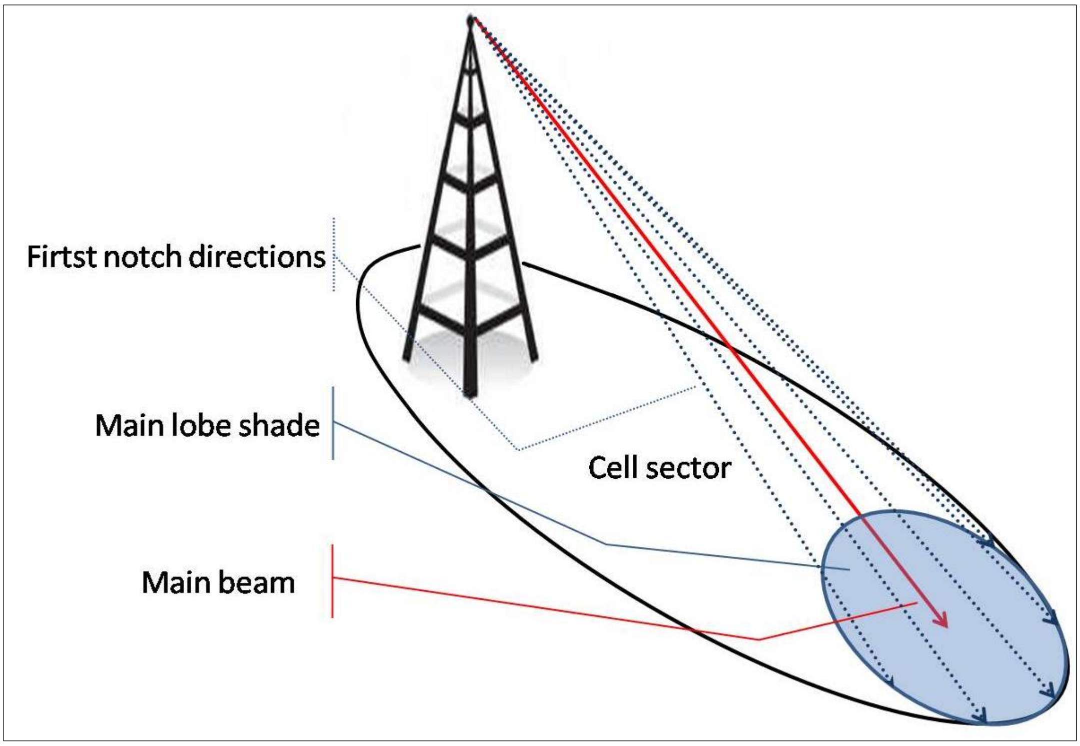

Figure 4.8 - First notch (6°) scheme

This method is enhanced with one slight variation, aimed at ensuring an easier handover process. In order to have more power in the handover zone (cell edge), the modified version matches the direction of the 3dB beam with the cell edge instead of the first notch direction.

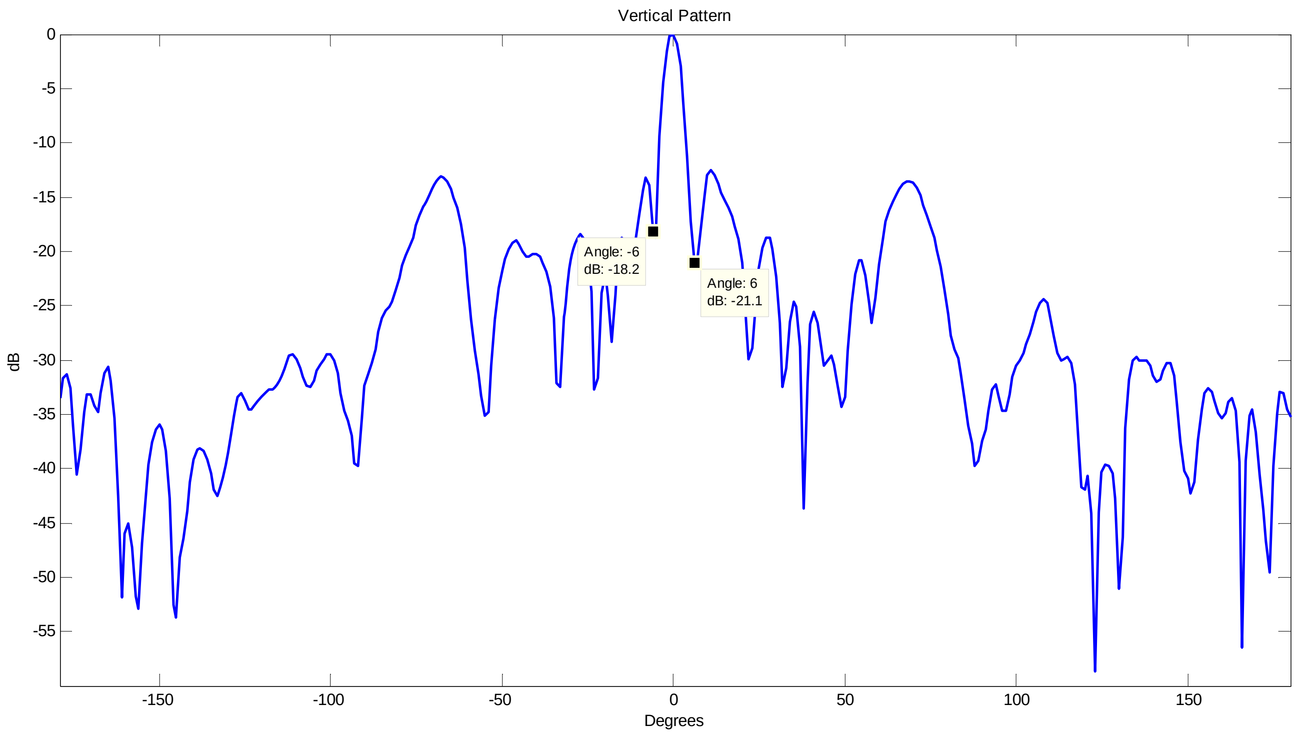

Figure 4.9 – Vertical pattern of a random antenna in the scenario - FN(6°)

In this case the direction corresponding to the first notch goes slightly out of the cell. The direction corresponding to a power intensity of -3dB in most of the antennas in this study case is 3° far from the direction of the main beam. Therefore this variation of the method is referred to as 'First notch (3°)' or 'FN (3°)'.

Figure 4.10 shows another random antenna pattern in which the direction of the 3dB beam is about 3° away from the main beam.

4.2. Simulations and results

Before presenting the results it is necessary to notice that Sonofon requires some restrictions on the simulations. These restrictions include: the minimum angle step, the maximum tilting angle and the type of tilting applied. For this reason, all obtained results are divided into two categories: the ideal case which strictly follows algorithms and the restricted case in which the Sonofon restrictions are added on top of the obtained results.

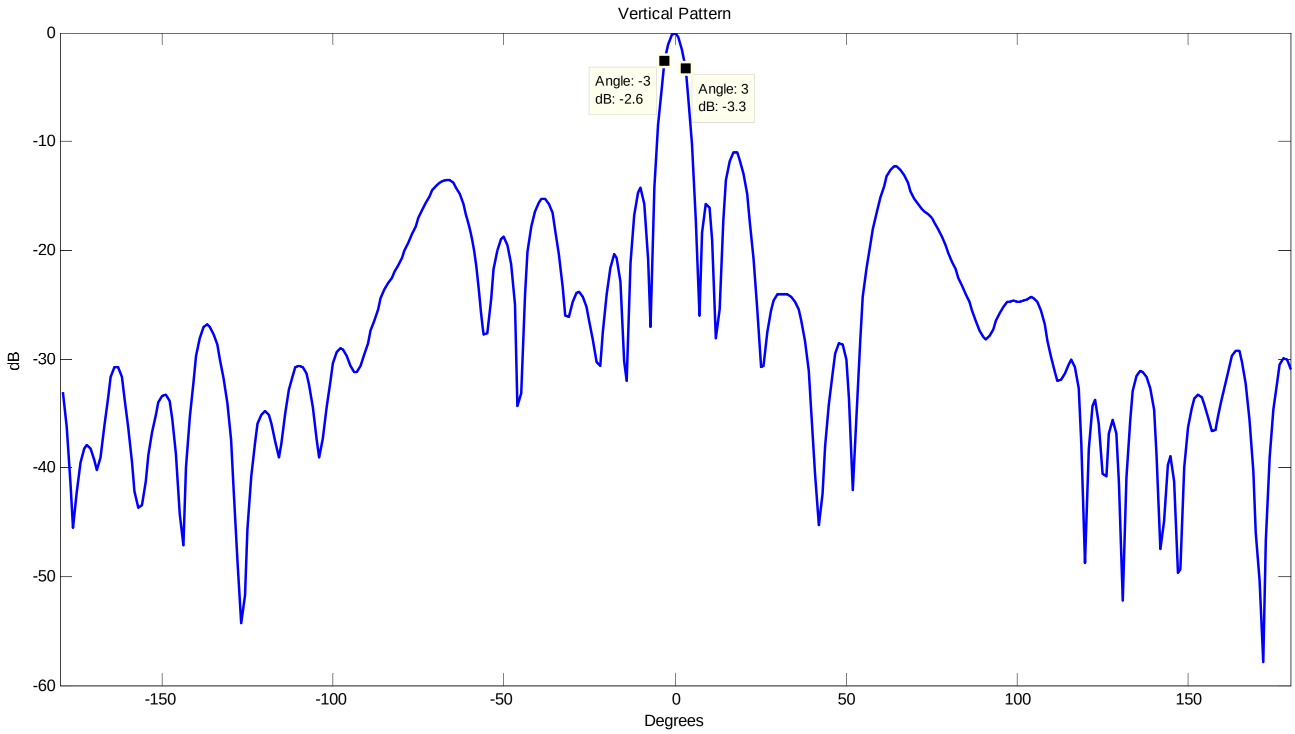

Figure 4.10 - Vertical pattern of a random antenna in the scenario - FN(3°)

Due to the fact that Sonofon has supplied vertical antenna patterns for electrical tilting in steps of 2 degrees, the minimum step angle requested is 2° as well. Besides that, the maximum allowed tilting angle, following the Sonofon explicit request, is 10°. In addition to the previous restrictions, any changes to the tilt of the antennas has to be applied as electrical tilt in order to apply the changes faster. This also allows the network operator to fall back to the former configuration easily. For simplicity purposes instead, mechanical tilting is applied throughout the simulations. Moreover every result in the restricted case is first reduced by 2 degrees, in order to not apply extreme changes to the current configuration, then modified until it fulfills the restrictions.

4.2.1. Ideal case

The objective of this section is to show and compare the result for all of the presented methods without applying any restriction. Starting by the 'Furthermost point' method Figure 4.11 compares the performances of the three variations of this algorithm in terms of ratio between signal power and interference plus noise power.

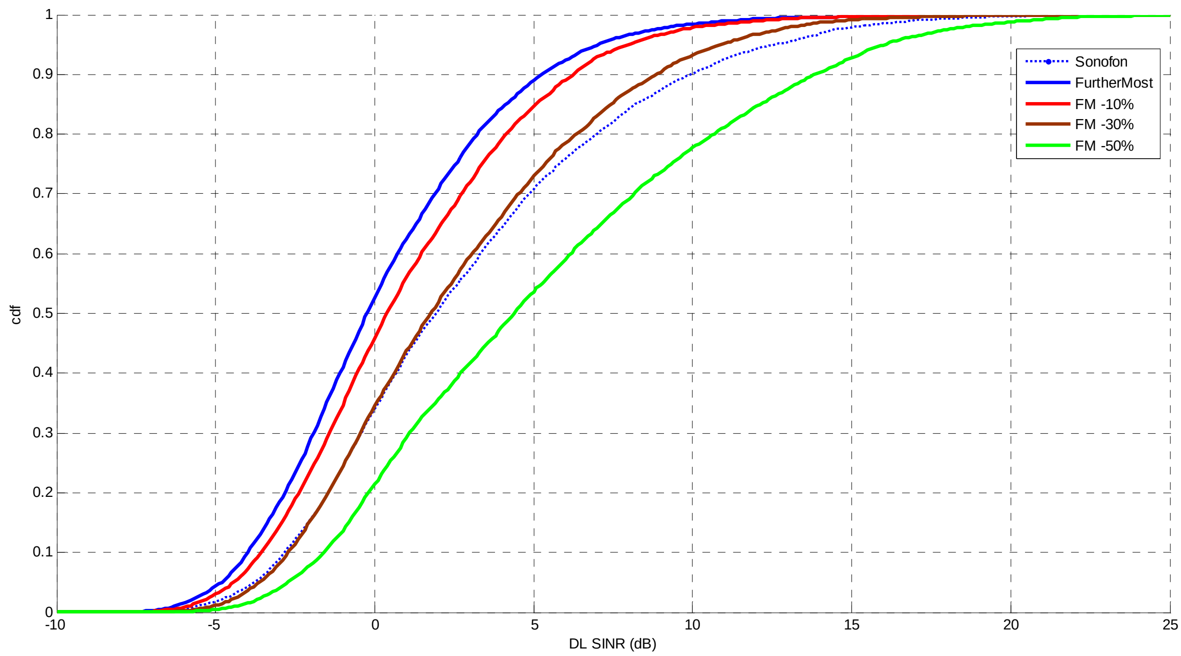

Figure 4.11 - FM method – SINR

The most efficient variation is the 'FM -50%' with an average gain of about 5dB respect to the original algorithm. For the regular cell, after applying this variation of this method, the main beam can be considered almost pointing towards the center of the sector. Figure 4.12 compares, on the other hand, these three variations in terms of throughput in downlink. It also confirms that the best performances are achieved with the 'Furthermost point -50%' with an average gain around 2Mbps more than the original algorithm.

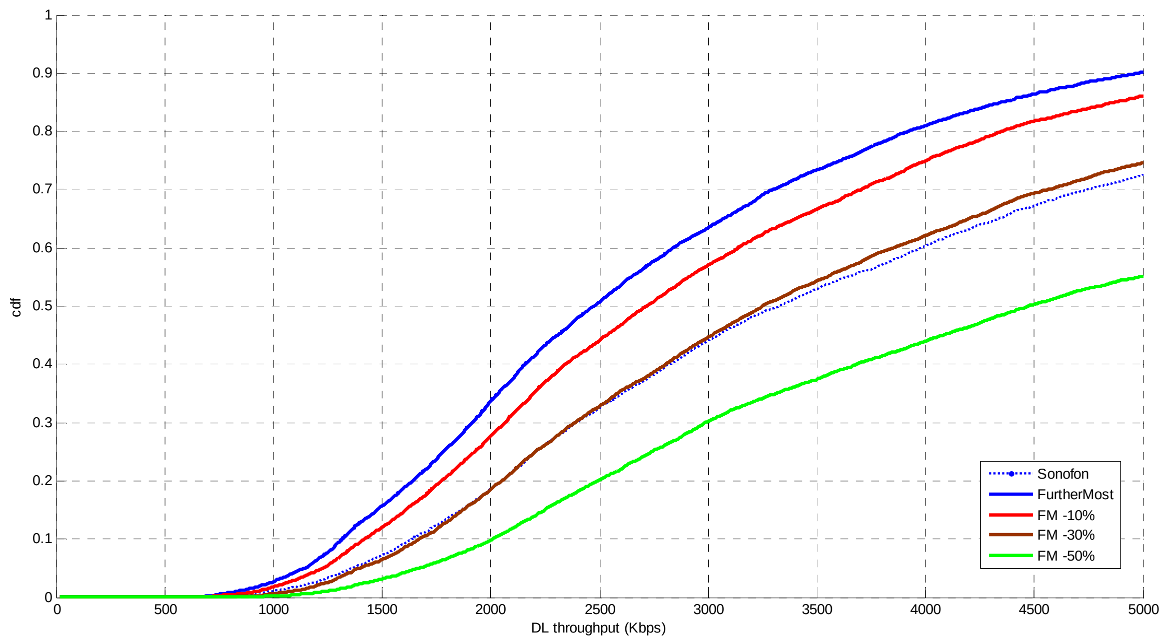

Figure 4.12 - FM method - DLTP

When pointing the main beam toward a point that as a distance from the antenna equal to the one that the furthermost point in the sector has, the upper part of the antenna vertical radiation pattern goes out of the cell. Therefore by using the three variations for reducing that distance, the performance get better and better. When the main lobe can be consider in an area almost in the middle of the sector, that means using the 'FM -50%' variation, the network shows the best performance.

Furthermore due to its better performances the 'FM -50%' method is the only one that is considered for comparison among the other algorithms.

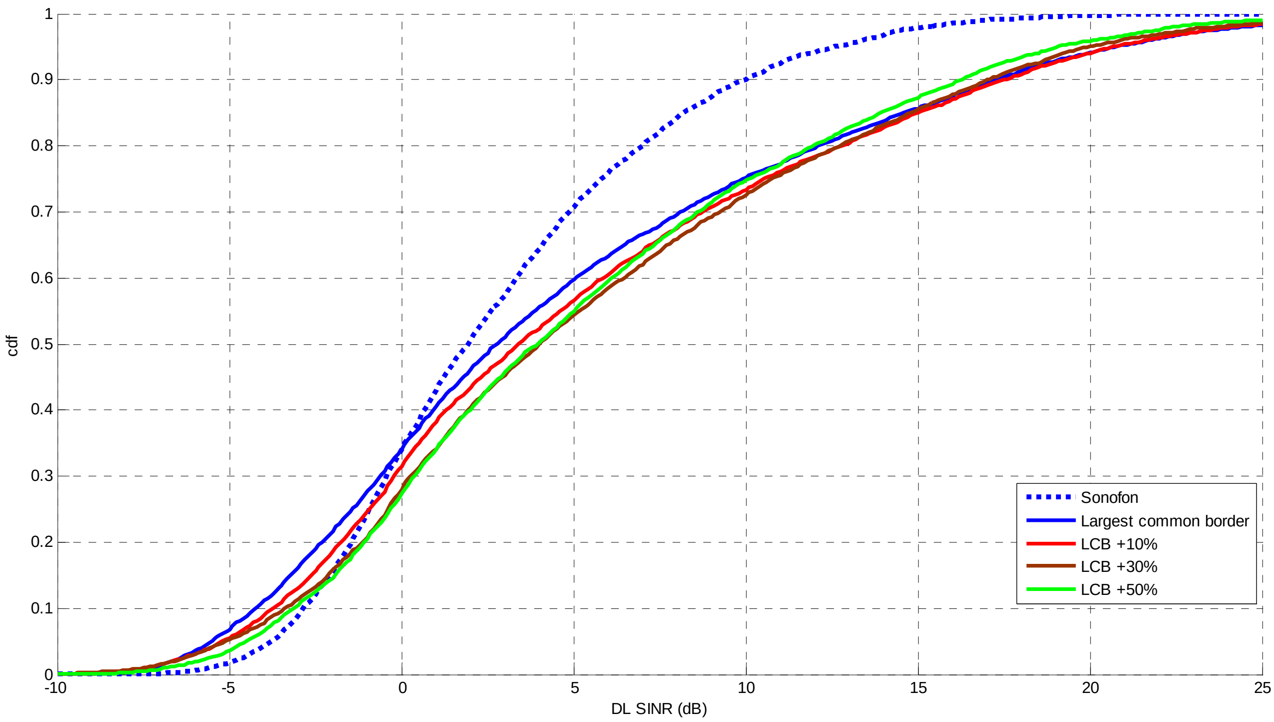

Figure 4.13 - LCB method – SINR

Figure 4.13 and Figure 4.14 compare the performances of the three variations of the largest common border method respectively in terms of SINR and DLTP. This method, even using variations, does not improve at all the performance in the zones which have a low level of SINR when using the angle values suggested by Sonofon. Paying attention to that part of the graph with low level of SINR is important because that zone corresponds to the edges of the sectors in the study area. Hence it is one of the zone that most requires enhancements.

Choosing the best variations for this method is difficult if using just Figure 4.13. Figure 4.14 helps to make a decision though.

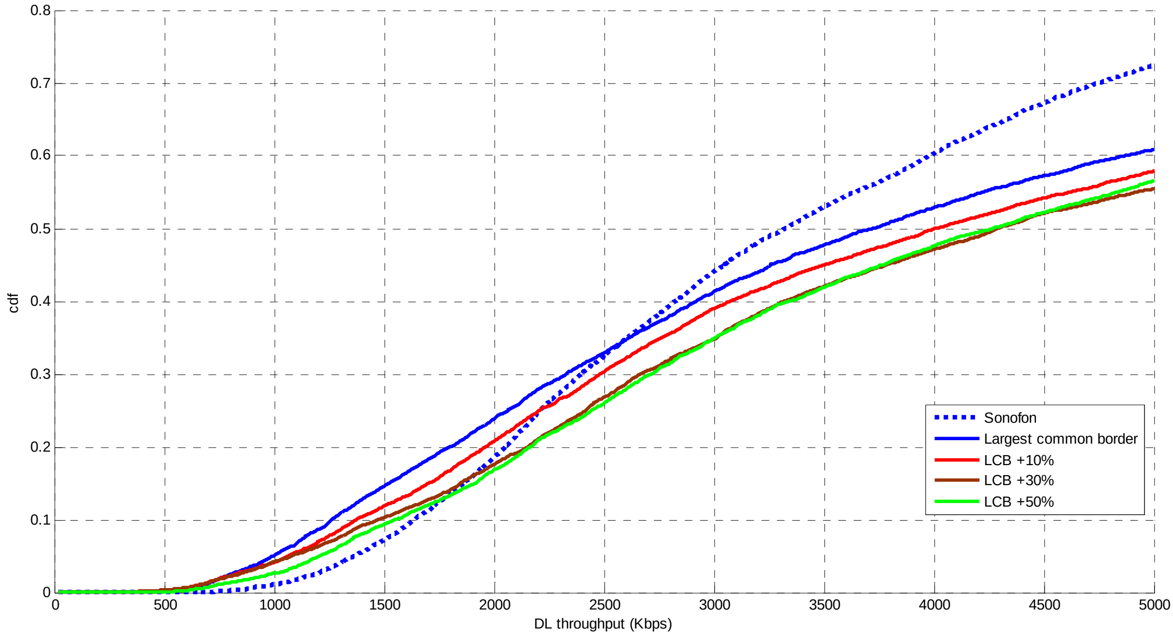

Figure 4.14 - LCB method – DLTP

In fact, even though neither of the lines in the graph shows performances better than the performance achieved with Sonofon configuration (in zone of the graph related to the cell borders), the green line related to the 'LCB +50%' method indicates a higher throughput than the throughput achieved by other methods, specially looking to the zone with low DLTP values.

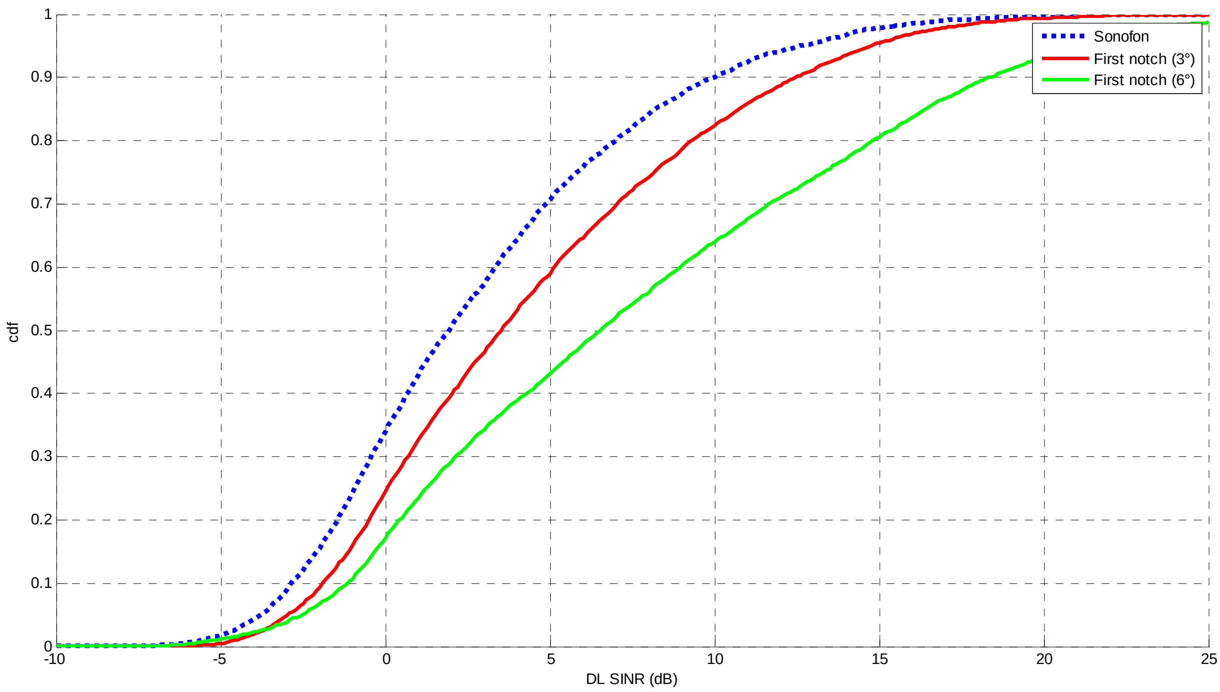

Figure 4.15 - FN method – SINR

Due to the higher performance reached by the use of 'Largest common border +50%', comparing with the other performance achieved by the other variations of the original method, furthermore on this work the 'LCB +50%' method is assumed as the best variation for this algorithm.

Focusing on the last method, that is the 'First notch', and its variations Figure 4.15 shows the performance in terms of signal to interference and noise ratio and Figure 4.16 shows them in terms of downlink throughput.

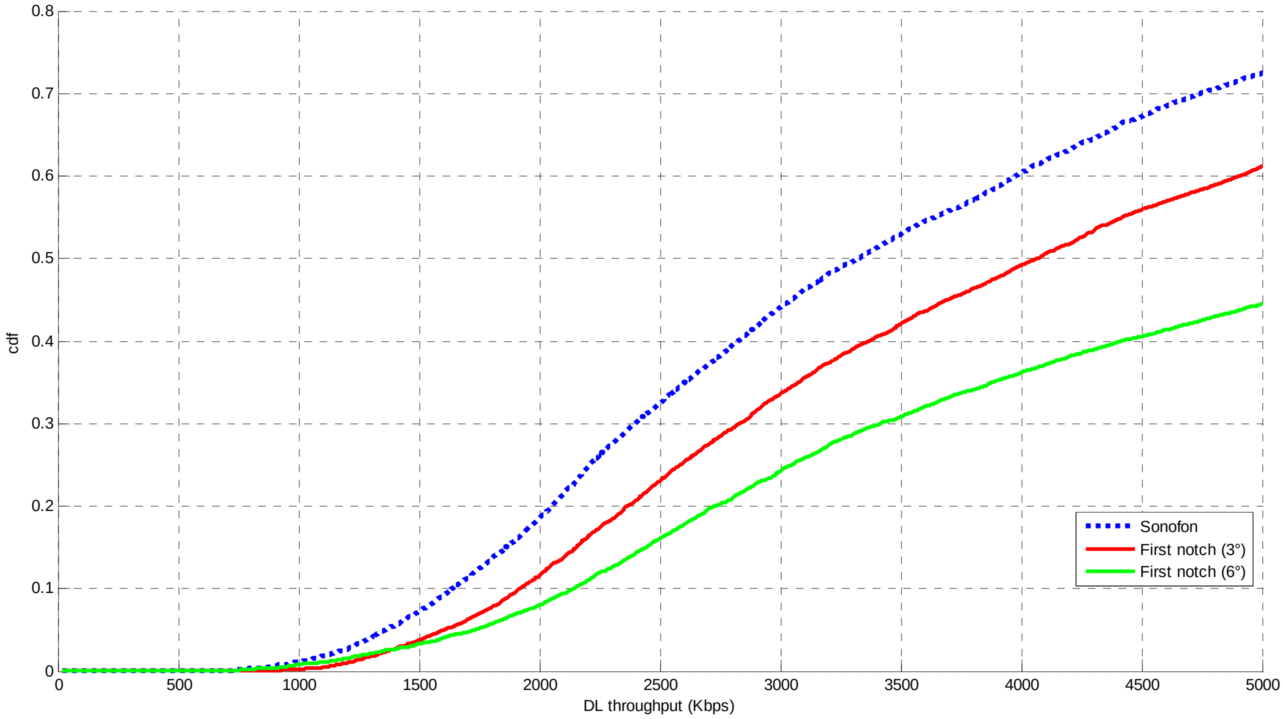

Figure 4.16 - FN method – DLTP

Both Figure 4.15 and Figure 4.16 indicate that the 'First notch (6°)' method performs better than the 'First notch (3°)' method. In fact the 'FN (3°)' method brings a SINR gain of about 2dB versus a gain of 5 dB reached by using the 'First notch (6°)' method. The main lobe it is totally pointed inside the cell when using the 'FN (6°)' method while. By using the 'FN (3°), part of the main lobe power goes outside the sector causing lower performance. Focusing on the downlink throughput brings to the same conclusion.

From now on this report will only take into account the performance of the 'First notch (6°)' method. This performance will be compared to the best performances obtained by using the angle values proposed by the other algorithms.

Figure 4.17 shows an histogram of the angles used by Sonofon (a) and the sub optimal angles obtained by the method which achieves the best performances (First notch (6°)) (b).

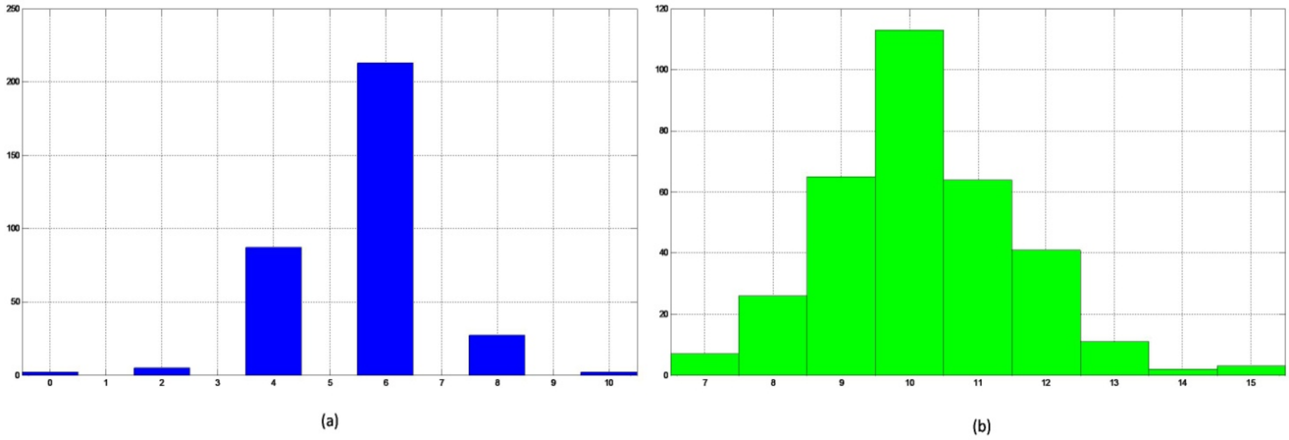

Figure 4.17 - Histogram of Sonofon and FN (6°) angle configurations without restrictions

It is possible to verify that the angles currently used in the Sonofon configuration have a lower average value when compared to proposed values. This means that with the new configuration the antenna are more tilted and more power is kept inside the sector. The zone with lowest SINR values, which usually are close to the border of the sector, has improved after tilting the antennas. Even though the Sonofon configuration tries to transmit more power towards the border area, the performances are worst. This is due to the fact that if each of the antenna uses this approach, all of the sectors are affected by an higher interference. This explain how, even if the antennas are more tilted, the quality of the communication improves also at the border of the cell. Besides that Figure 4.17 clearly shows the minimum angle step of 2° used by Sonofon in selecting their tilting angles that is one of the requirements for the restricted case.

4.2.2. Restricted case

This paragraph shows the results obtained by each method applying the restrictions described in the introduction of this section. Figure 4.18 and Figure 4.19 present the results for the ‘Furthermost point’ method in terms of SINR and DLTP respectively.

The ‘FM -50%’ method has still the best performance among the modified algorithms of the same method. Following the restriction it cannot reach as good performances as the ones yielded by using the Sonofon configuration though. This is because ideally the ‘Furthermost point’ precisely tunes the position of the main lobe. When applying the restriction which imposes an angle step value of 2°, the method loses in precision skill and the performance gets worst.

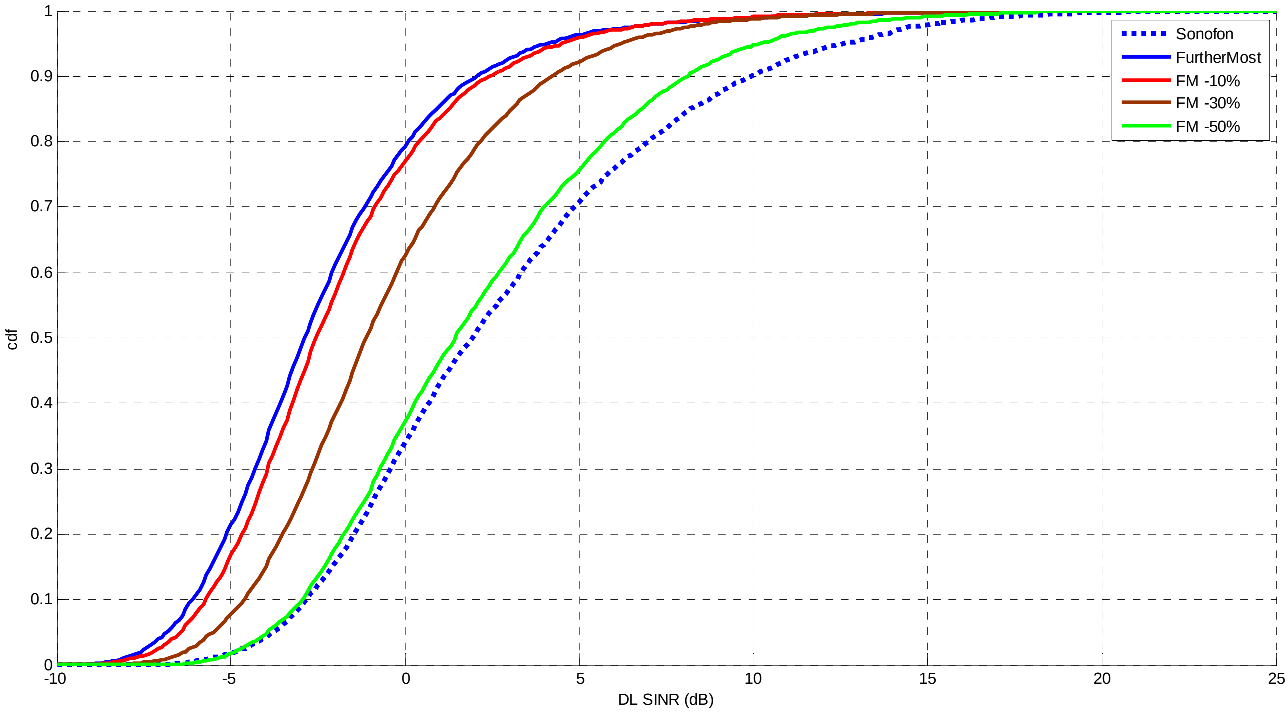

Figure 4.18 - FM method with restrictions – SINR

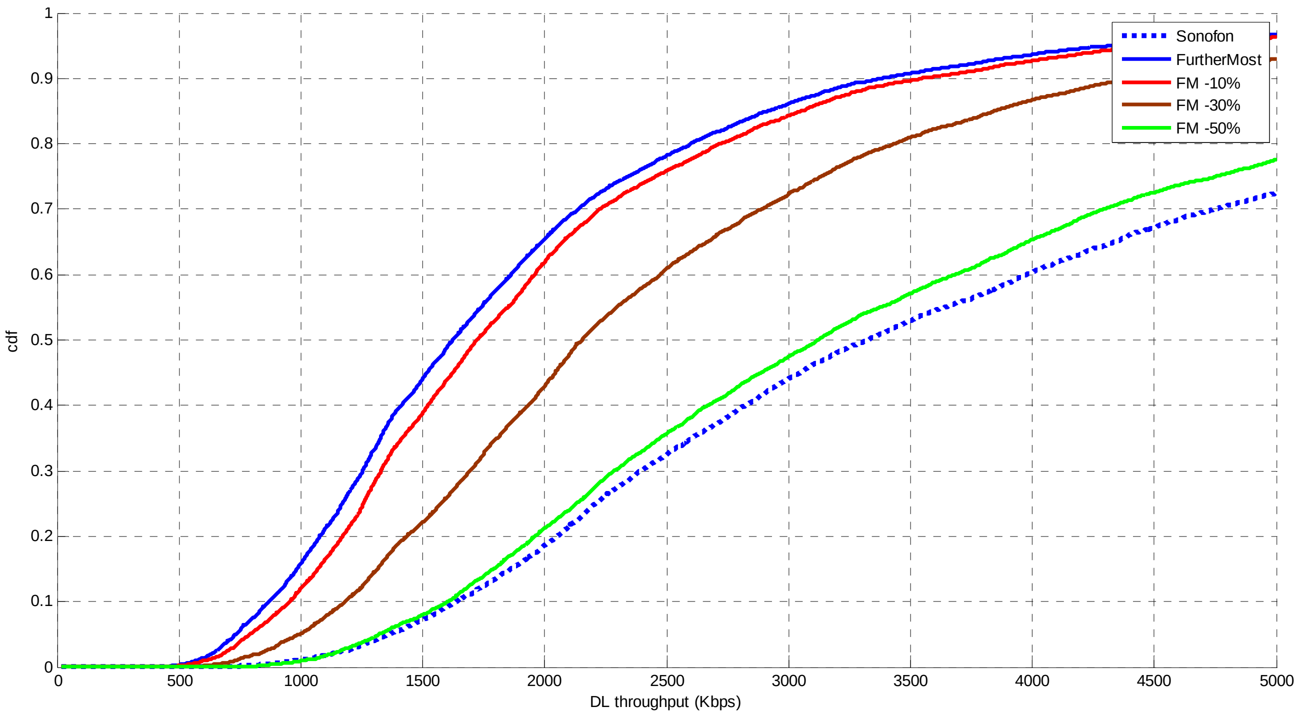

Figure 4.19 - FM method with restrictions – DLTP

Figure 4.20 and Figure 4.21 show the behavior of the 'Largest common border' method considering the SINR and the downlink throughput respectively. This method receives an important enhancement by applying the Sonofon restrictions. This fact is a further proof that the 'LCB' method does not work properly. In fact, the restriction are suppose to get the performance worse by limiting the maximum allowed angle value and imposing a minimum step angle. The Sonofon restrictions appreciably improves the performance that the network can reach by using this method.

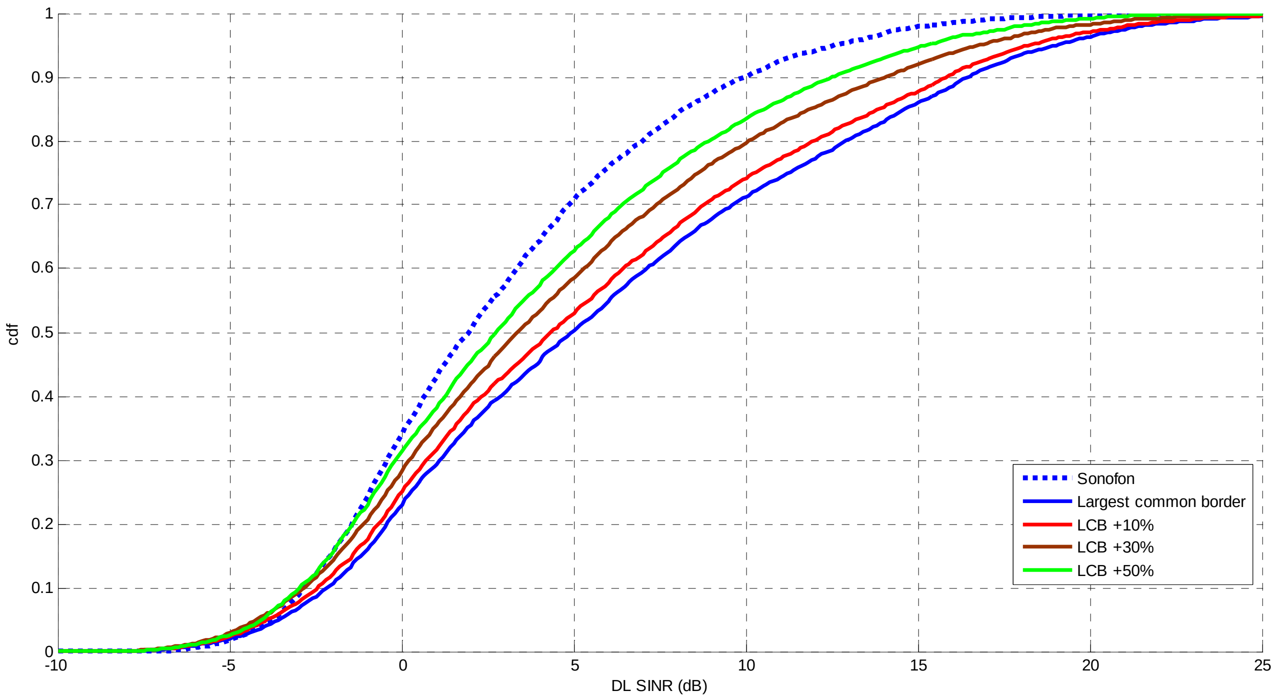

Figure 4.20 - LCB method with restrictions – SINR

Figure 4.22 shows a zoom of the Figure 4.20 relative to the largest common border and specify that only the original method have better performances than the performance that Sonofon configuration has in the low range of the graph. To better understand this, a threshold is chosen on the graph and used to compare the various results.

The value corresponding to the 5% of the distribution is generally chosen. Over the network this would generally represent the users towards the cell edge. By using this reference, the original 'Largest common border' method is the only one that, among its own variations, outperforms the configuration used by Sonofon.

Figure 4.23 shows the behavior of the 'First notch' method considering just the signal to interference plus noise ratio. When using the restrictions, the 'First notch (3°)' does not even reach the performances achieved by Sonofon current configuration. In the ideal case it gains around 2dB instead. Even though the 'First notch (6°)' method has little degradations on its performance in the restricted case, it still shows improvements when comparing its results with the performance achieved applying the Sonofon configuration.

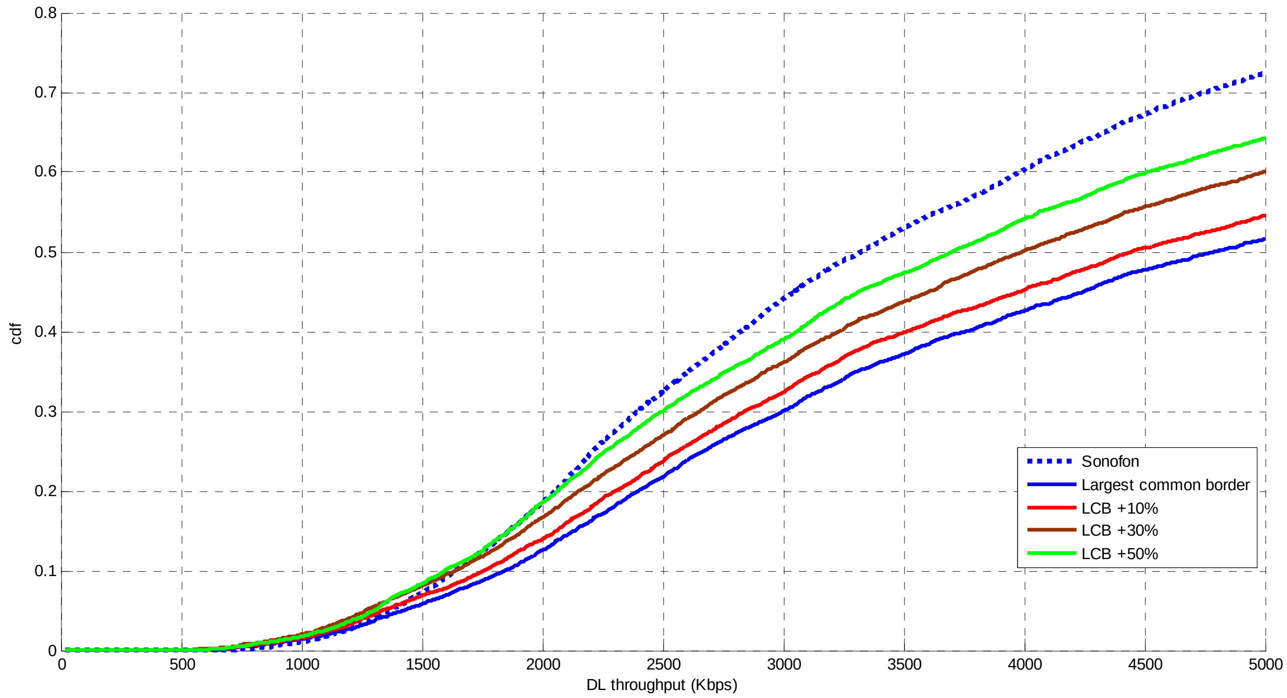

Figure 4.21 - LCB method with restrictions – DLTP

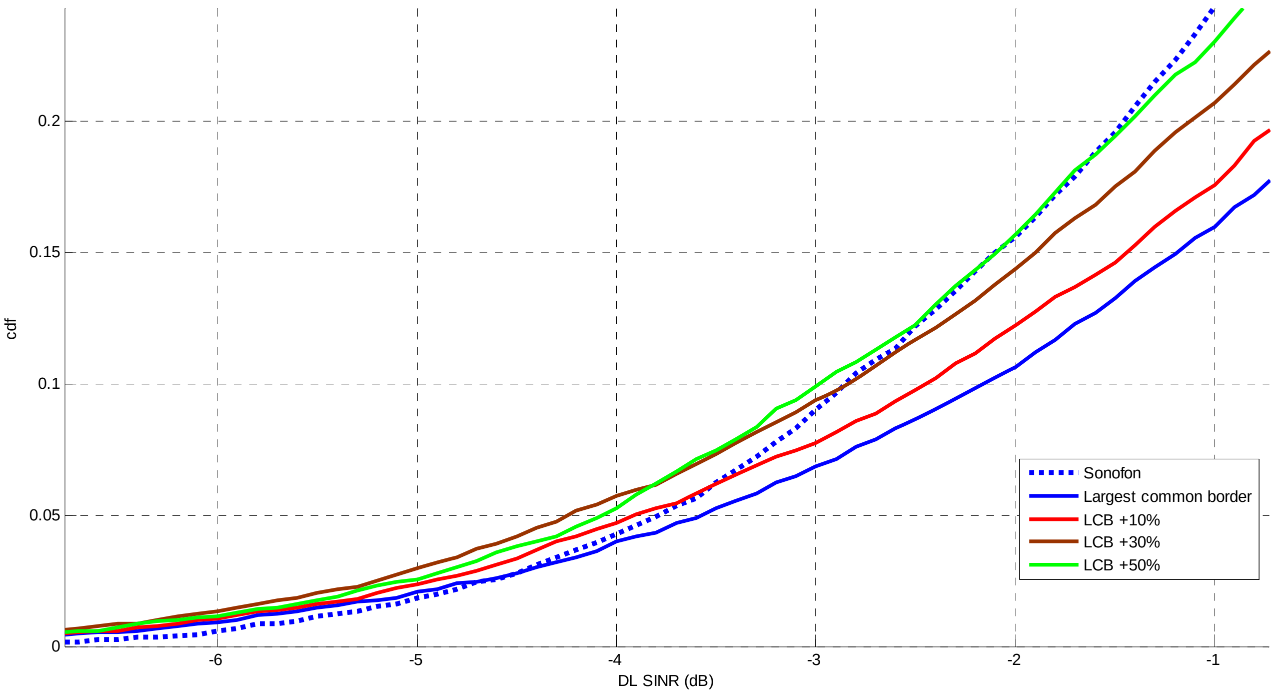

Figure 4.22 - LCB Zoom of Figure 4.20

All of the methods loose quality and performance when the restrictions are applied because they are based on geometric theories and calculations. When the restrictions change the values obtained from the simulations, they basically use a wrong result to solve the geometrical problem that is behind all of the methods. Hence, the decrease with the performance is to be considered predictable.

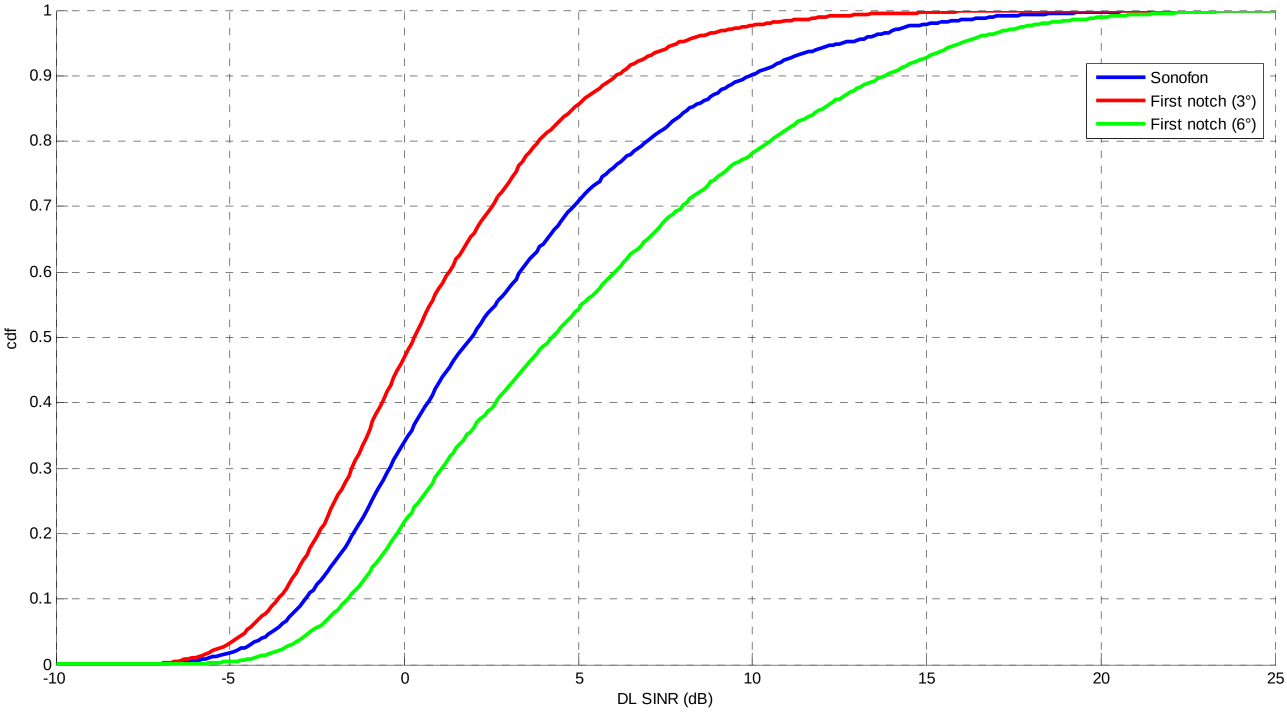

Figure 4.23 - FN method with restrictions – SINR

Figure 4.24 presents a comparison between the angles used by the Sonofon configuration and the angles used by the first notch (6°) configuration with the restrictions. The mean value of the angles in the first notch configuration is higher than the ones used by Sonofon, also after applying all of the restrictions.

It is interesting to note also that, while in the Sonofon configuration all the even values of the angle are used (0° included), in the first notch (6°) configuration the smallest used (just by less than 10 antenna) value is 4°. By using the angle configuration that the 'First notch (6°)' method suggests, there will be more than 80 antennas with a tilting angle of 6°. The most common tilting angle suggested is that of 8°, with about 180 antennas selected for this setting.

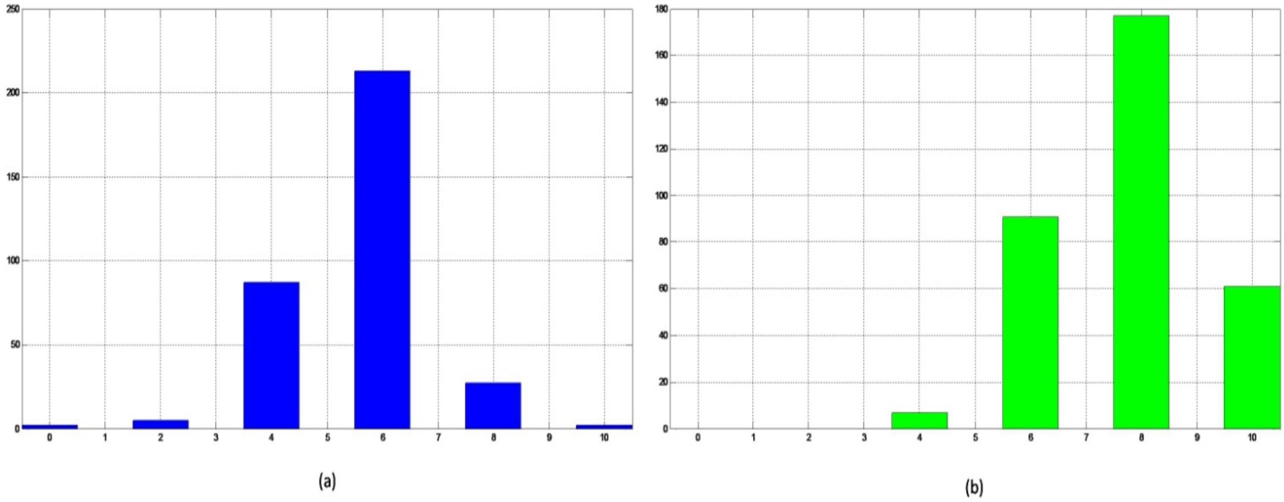

Figure 4.24 - Histogram of Sonofon and FN (6°) angle configurations with restrictions

4.3. Analysis of the results

In order to easier analyze the algorithms Figure 4.25 and Figure 4.26 show in term of SINR only the variations that have the best performances for each method in the ideal case and in the restricted case respectively.

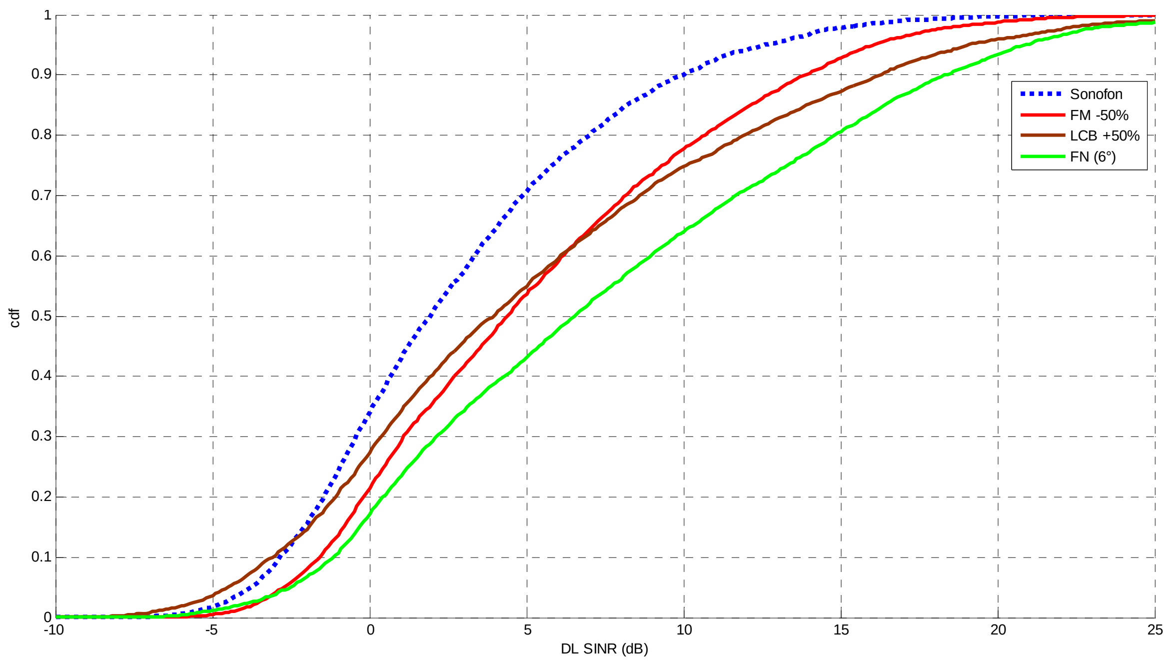

Figure 4.25 - Comparison among best methods - ideal case – SINR

Two algorithms out of the proposed methods perform better than the Sonofon configuration in the ideal case. The 'Largest common border +50%' method is the only algorithm that cannot reach the results that the Sonofon configuration does. In fact, in the low part of the SINR axis the brown curve goes worse than all of the other three curves. Having a good behavior in this part of the graph is really important for a network configuration because it shows the performance of network for the zones that, at the current moment, have the worst conditions.

Considering the ideal case, both 'Furthermost +50%' and 'First notch (6°)' show some improvement over the results obtained by using the current Sonofon tilting angles. Both methods point the main lobe completely inside the sector. The 'FM -50%' method keeps it about in the middle of the sector whereas the 'FN (6°) methods points the main lobe completely to the zone at the border of the cell. The success of one approach over the other one can depend on cell shapes and their distribution in the study area. Beside, it is only the 'First notch (6°)' method that performs well in both the ideal and restricted cases.

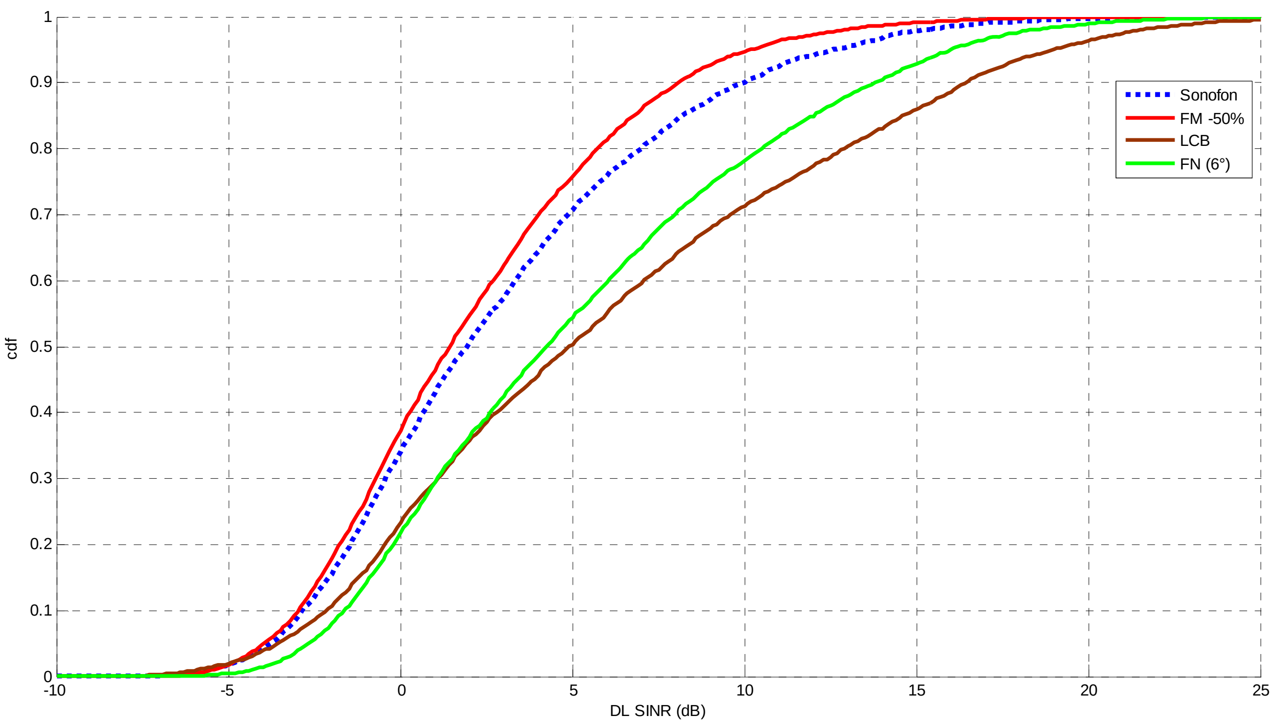

Figure 4.26 - Comparison among best methods - restricted case – SINR

A similar analysis can be done focusing on the throughput in downlink. Figure 4.27 and Figure 4.28 show respectively the ideal and the restricted behavior of the best proposed algorithms in terms of DLTP.

As previously noted in the SINR curves, the 'Furthermost -50%' and 'First notch (6°)' methods are the ones performing the best under the ideal case. On the other hand, the brown curve still indicates the 'Largest common border +50%' as the worst algorithm in ideal conditions.

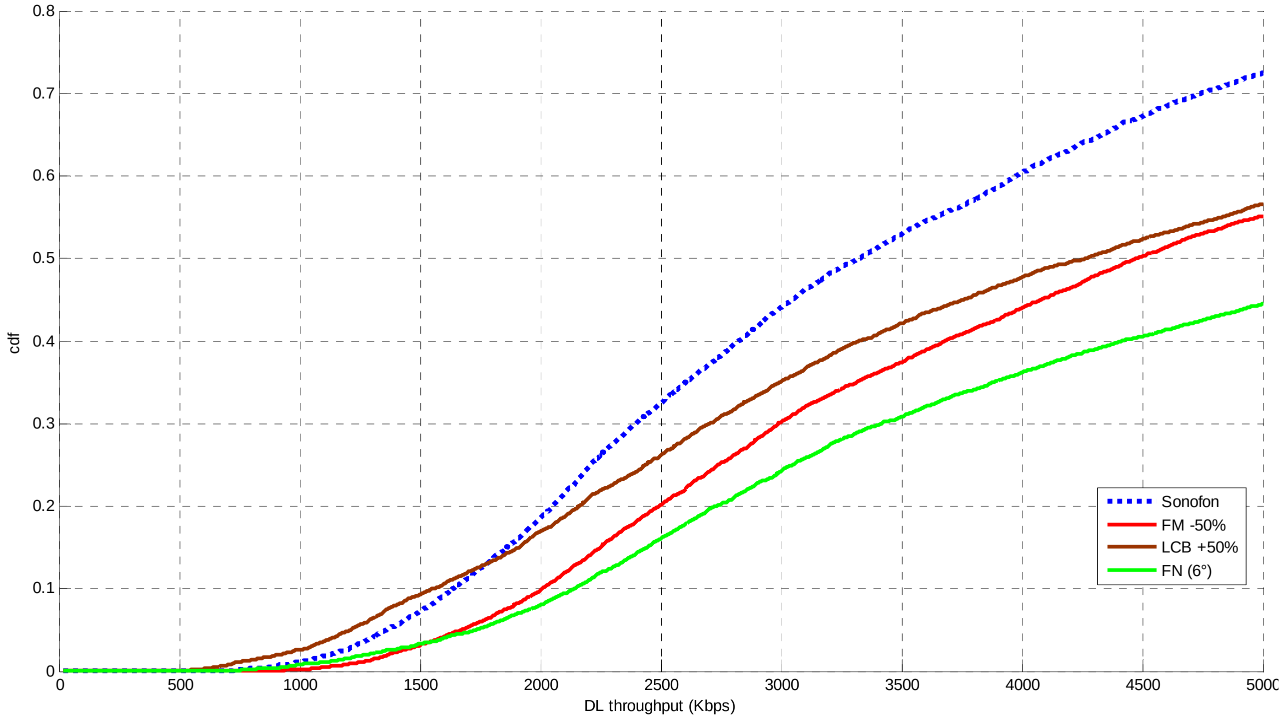

Figure 4.27 - Comparison among best methods - ideal case – DLTP

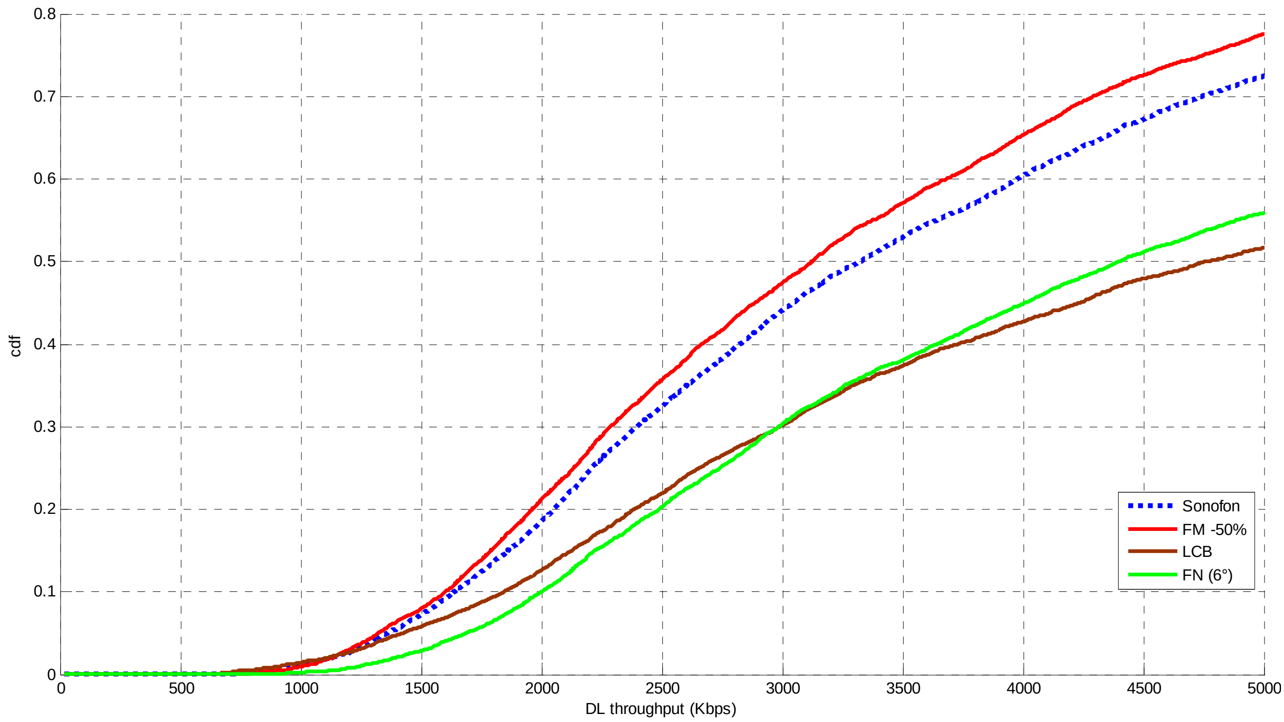

Figure 4.28 - Comparison among best methods - restricted case – DLTP

It is possible to notice that the only method that improves its own performances after applying the restriction is the ‘Longest common border’. On the other hand, by applying the restriction the ‘Furthermost point +50%’ method shows an important degradation of performances. The red line related to the ‘FM +50%’ algorithm shows that this method get worse results all over the graph trend. It cannot even reach the performances that the current Sonofon configuration can ensure. Figure 4.29 shows a comparison between the values of the angles used by the ‘Longest common border’ method under the ideal case (a) as well as under the above mentioned restrictions (b). In the ideal case the average of the values is much higher than in the restricted case with a maximum angle that is bigger than 25 degrees. This result draws to the conclusion that the ‘LCB’ makes the main bean of the antennas point in a zone too close to the antenna site. By using the restriction, the ‘Largest common border’ corrects the position where to point the main beam. In fact, most of the angle values are reduced in order to point the main lobe of the antennas towards a zone further from each corresponding antenna site.

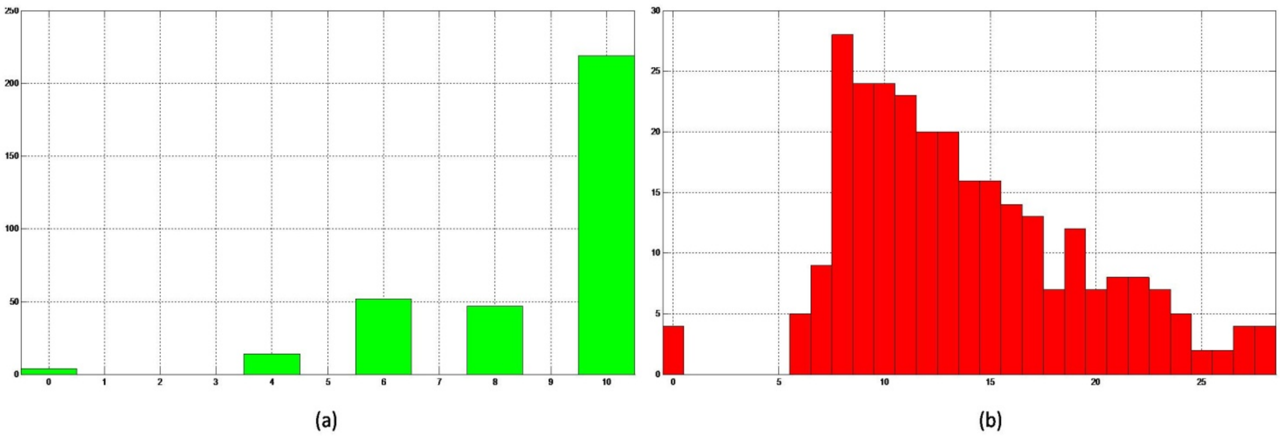

Figure 4.29 - Histogram of LCB angle configurations with (a) and without (b) restrictions

The ‘FN (6°)’ method is the only one that manages to keep good performances even after applying the restrictions. Hence Figure 4.30 shows a comparison between the configuration suggested by this algorithm before (b) and after (a) using the restrictions. Even before applying the restriction the ‘FN (6°)’ method use angles values approximately smaller than 18 degrees and an average slightly bigger than 10°.

All the results draw to the conclusion that the ‘FN (6°)’ method performs better than the current Sonofon configuration and the other algorithms proposed.

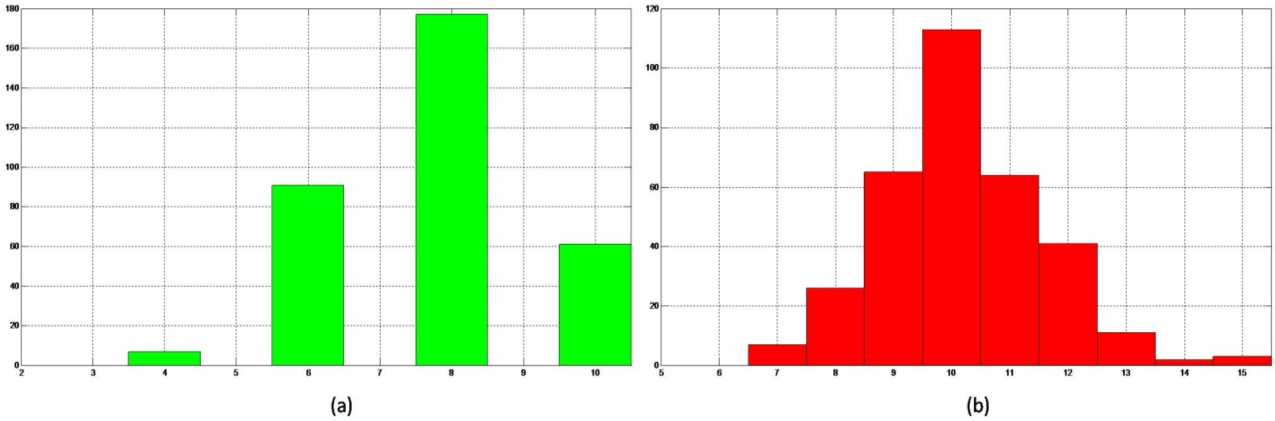

Figure 4.30 - Histogram of FN (6°) angles configurations with (a) and without (b) restrictions

Applying the restrictions slightly affects this method but a major effect was noted on the performances of the 'Furthermost point' and the 'Largest common border' methods. After the restrictions are applied to the 'FM' algorithm the overall performances is noted to be worse than that achieved with the current Sonofon configuration. On the other hand, the 'LCB' method shows some improvements, mainly due to the corrections that the restrictions introduce. Standing on this result, the 'FN (6°)' notch is the method which works the best among all of the presented methods. In the ideal case it provides very high performance and it manages to keep them even after applying the restrictions.

The restricted case, which is the scenario most like the real situation, shows two methods that outperform the Sonofon configuration. Even though the restrictions are the main reasons that make the 'LCB' method get better in the restricted case, this method shows good improvements in the average performance of the network. Although the 'LCB' method does not work properly yet and it cannot be used in the optimization phase, the tilting angle configuration, which this algorithm gives as result of the simulations, could be used in the analyzed area. The 'LCB' algorithm does not provide a general procedure for a random irregular network though.

5. Conclusions and future work

This project has dealt with the analysis of a number of antenna tilting algorithms for optimizing the coverage and capacity of irregular network. The need of analyzing this aspect comes out as a requirement of a bigger project that deals with network optimization and evolution.

Three methods, each one presenting its own variations, have been presented. Each method, and their variations, have been developed in MATLAB® and imported in the SNEPATool simulator. The suggested methods have been tested using two different scenarios: the ideal case and the real case in which some restrictions have been imposed by the network operator, Sonofon.

For the ideal case two methods improve the performance of Sonofon's configuration which are the 'FM -50%' method and the 'FN (6°)' method. When analyzing the restricted cases there are also two methods that outperforms Sonofon's current configuration. The 'FN (6°)' shows an improvement also when the restrictions are applied. Together with this algorithm it was the 'LCB' method that achieved a higher performance.

If just the best configuration over all of the proposed ones can be tested in the real network, the best candidate is the one suggested by the 'First notch (6°) methods because it demonstrates to work and to get good result in both the study cases providing results very slightly different.

While some of the investigated algorithms showed an improvement in performance, what is missing is a better understanding about the limit of how much a network can be improved through antenna tilting. Future studies can look at this problem and try to quantify an upper bound limit that shows the maximum improvement in performance that a network can obtain by optimizing antenna tilting. This could be done through a more lengthy process that slowly modifies one antenna at a time and checks for the effects, that such a small change has over the specific cell as well as over the whole network. In the case that there is an improvement this setting is kept, otherwise the previous setting is restored. This will provide a measuring stick against which the investigated algorithms can be compared to. How close the results are to this upper limit will decide on the efficiency of the developed algorithms.

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