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Master’s Thesis

Inter-Cell Interference Cancellation using Beamforming Technique

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Dédicace

Je dédie ce travail à tous ceux qui

m'ont soutenu de près et de loin,

A ma mère

A mes sœurs et mes frères

A mes proches

A tous mes amis

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ملخص

في الشبكات الخلوية اللاسلكية، ونظرا للطلب المتزايد على معدلات عالية للبيانات بسبب تقدم التكنولوجيا مما يؤدي الى عدم كفاية الطيف الترددي. لذلك لا بد تقنية متقدمة لتغطية مجموعة واسعة من المستخدمين مع الأداء البارز والأمثل. والهدف من هذا العمل هو دراسة ومحاكاة حالة إلغاء التداخل بين الخلايا في أنظمة الاتصالات اللاسلكية المتنقلة باستخدام تكوين الشعاع. محاكاة بيئة متعددة الخلايا باستخدام برامج المحاكاة وتصور واجهة المستخدم الرسومية من أجل إظهار والسيطرة على كل من بيئة المحاكاة والنتائج. كما سيتضح، يتم الحصول على نتائج مرضية باستخدام تكوين الشعاع من حيث CIR.

كلمات البحث: تكوين الشعاع، واجهة المستخدم الرسومية ، التداخل بين الخلايا، محاكاة،

Résumé

Dans les réseaux cellulaires sans fil, la demande pour des débits élevés et de capacité a été soulevée en raison de l'avancement de la technologie. Cela conduit à l'insuffisance du spectre; donc une technique avancée est nécessaire pour couvrir un vaste nombre d'utilisateurs avec des performances éminent et optimale. Le but de ce travail est d'étudier et de simuler le cas d'annulation d'interférence inter-cellules dans des systèmes de communications radio mobiles en utilisant la technique de beamforming. Un environnement de réseau multicellulaire est simulé à l'aide d'un logiciel de simulation et une interface d’utilisateur graphique est conçue afin de montrer et de contrôler à la fois l'environnement de simulation et les résultats. Comme on le verra, des résultats satisfaisants en termes de CIR sont obtenus en utilisant le beamforming.

Mots-clés: Beamforming; Interférence inter-cellule; simulation; CIR; GUI; GSM

Abstract

In wireless cellular networks, the demand for high data rates and capacity has been raised due to the advancement of technology. This leads to the insufficiency spectrum; therefore an advanced technique is needed to cover a vast range of users with eminent and optimum performance. The aim of this work is to study and simulate the inter-cell interference cancellation case in radio mobile communications systems using beamforming. A multi- cell network environment is simulated using a simulation software and a Graphical User Interface is conceived in order to show and control both simulation environment and results. As will be shown, satisfying results are obtained using beamforming in terms of CIR.

Keywords: Beamforming; Inter-cell interference; simulation; CIR; GUI

List of acronyms and abbreviations

1G	First Generation
3G	Third Generation
4G	Fourth Generation
5G	Fifth Generation
AWGN	Additive White Gaussian Noise
BS	Base Station
BTS	Base Transceiver Station
CIR	Carrier to Interference to Noise Ratio
CQI	Channel Quality Indication
FH	Frequency Hopping
FRF	Frequency Reuse Factor
GSM	Global System for Mobile Communication
GUI	Graphical User Interface
GUIDE	Graphical User Interface Development Environment
ICI	Inter-cell Interference
IMT-A	International Mobile Transmission-Advanced
LTE	Long Term Evolution
MATLAB®	Matrix laboratory
MIMO	Multiple Input Multiple Output
MS	Mobile Station
OFDM	Orthogonal Frequency Division Multiple Access
PFR	Partial Frequency Re-use
Rx	Reception
SFR	Soft Frequency Re-use
SINR	Signal to Interference to Noise Ratio

SNR	Signal Noise Ratio
Tx	Transmission
UE	User Equipment
UP	Uplink
WiMAX	Worldwide Interoperability for Microwave Access

List of symbols

dB	Decibels
dBm	Decibels-mill watts
θ	Theta
λ	Wave length
GHz	Giga Hertz
σ	Sigma
α	Alpha
Mbit/s	Mega Bits per second
f	Frequency

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Chapter 1 Introduction

1.1 Background and Motivation

The success of 4th Generation wireless systems which are currently deployed (e.g LTE, WiMAX, LTE-Advanced) is dependent on how far they adhere to the specifications of IMT-A[1] In such challenging condition, it is convenient to consider the Shannon equation and find out which part of it should be exploited to improve channel capacity:

$C = B.\min(M_T, M_R)\,.\,log_2(1 + SINR)$ [1]

Where M_T and M_R are the number of Tx antennas and Rx antennas respectively.

1. It is impossible and illegal to increase the bandwidth (B) as it is a fixed portion granted by the government.
2. MIMO is theoretically a brilliant and promising technology which enhances both the efficiency and performance of the system. However, from practical point of view, its performance can be severely degraded by interference.
3. Increasing SINR in a wireless system requires either increasing the signal power or reducing the interference. Increasing the transmit power would certainly increase the interference in the other cells and affect the whole system performance.

The alarming increase in MSs and the need to high throughput which has been achieved by the improvement in network platforms from 1G to LTE, WiMAX and 4G networks entails that highly efficient methods are employed to counteract interference to achieve these high bit rates. From the above brief discussion, it is clear that interference is the serious problem that holds all the above parameters from a good contribution to the channel capacity and then to the system capacity.

Mitigating the interference or reducing it significantly is surely going to lead to a successful ubiquitous high data rate system.

1.2 About this work

In this thesis, inter-cell interference problem is addressed using an Inter-Cell Interference Cancellation scheme based on spatial filtering.The problem of inter-cell interference is discussed together with the various techniques that are used to reduce/eliminate this phenomenon.

Inter-cell interference happens when the same frequency is used by MSs in adjacent cells[2]. To combat this problem some inter-cell interference mitigation techniques can be used including inter-cell co-ordination techniques and inter-cell interference cancellation techniques.

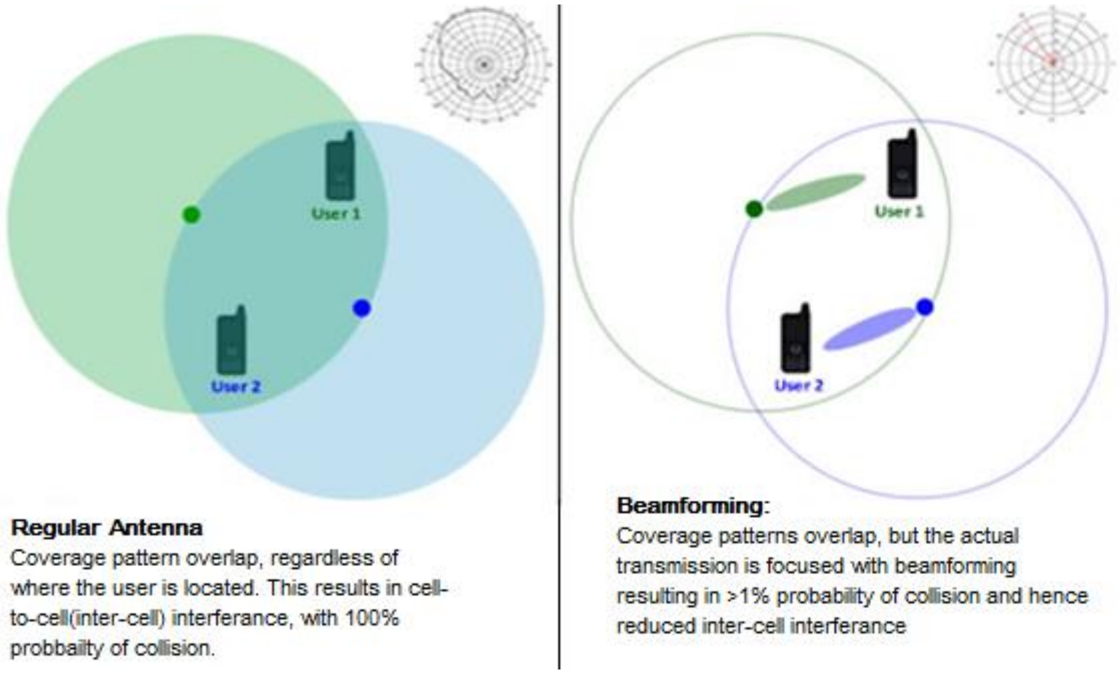


Figure 1: Beamforming as an inter-cell interference cancellation technique

Inter-cell interference coordination (ICIC) mechanisms aim at reducing the collision probabilities and at mitigating the SINR degradation that such collisions may cause in order to improve the system performance and increase the overall bit rates of the cell and its cell edge users[2]. A wide range of techniques are used in order to improve the throughput of the cell-edge users by reducing or suppressing the ICI. Interference mitigation techniques include : (1) Interference randomization, where some cell-specific scrambling, interleaving, or frequency-hopping (spread spectrum) , (2) interference cancelation: where the interference signals are detected and subtracted from the desired received signal, or if multiple antenna system is employed, the receiver can select the best quality signal among the various received signals , (3) adaptive beamforming, as shown in figure 1: where the antenna can dynamically change its radiation pattern depending on the interference levels.

1.3 Structure of the thesis

The remainder of this thesis is organized as follows:

Chapter 2 gives a comprehensive overview of some of the inter-cell Interference mitigation techniques that are at present being employed in various network systems and some that are being proposed for the 5G network which is to be deployed probably in 2020[3]. The techniques discussed are but not limited to: Frequency Reuse based schemes, Intelligent Reuse schemes, Inter-cell coordination schemes and Beamforming.

In Chapter 3, we will further analyse the technique of Beamforming with the aid of a simulation environment. A Graphical User Interface is built in the objective of showing both the simulation strategy and results as Carrier to Interference Ratio when we have an uplink scenario with and without power control.

1.4 Summary

In this chapter, the background and motivation, problem to be studied, a synopsis of the observed results and the organization of this thesis have been provided. The next chapter presents an overview of the current methods of interference avoidance.

Chapter 2 Inter-cell Interference Mitigation Techniques

2.1 Introduction

Generally speaking, cellular mobile communication systems suffer from two major classes of interference, namely, intra-cell interference and inter-cell interference[2]. In the former, interference is caused between frequency channels within the same cell due to adjacency of both frequencies and power leakage from one channel to an adjacent channel. In the latter, however, interference is caused between a frequency channel in one cell and the same frequency channel used in another adjacent cell. Even with almost no intra-cell interference, inter-cell interference (ICI) still presents a great challenge that greatly limits the system performance, especially for users located at the cell edge. Inter-cell interference coordination (ICIC) mechanisms aim at reducing the collision probabilities and at mitigating the SINR degradation that such collisions may cause in order to improve the system performance and increase the overall bit rates of the cell and its cell edge users. Generally speaking, ICIC techniques can be classified into mitigation and avoidance techniques. In this chapter we will discuss some Inter-cell Interference Mitigation/Avoidance Techniques that can be used to minimize the effects of inter-cell interference. We go on to explain in detail the beamforming technique in the last section of this chapter. The beamforming technique will be exploited further in chapter 3.

2.2 Interference Avoidance Techniques

Interference avoidance schemes represent the frequency reuse planning algorithms used by the network elements to restrict or allocate certain resources (in both frequency and time domains) and power levels among users in different cells. The objective of these frequency reuse planning algorithms is to increase the SINR, and hence, allow the system to support as many users as possible. An overview of these techniques are given in the following tree diagram in figure 2:

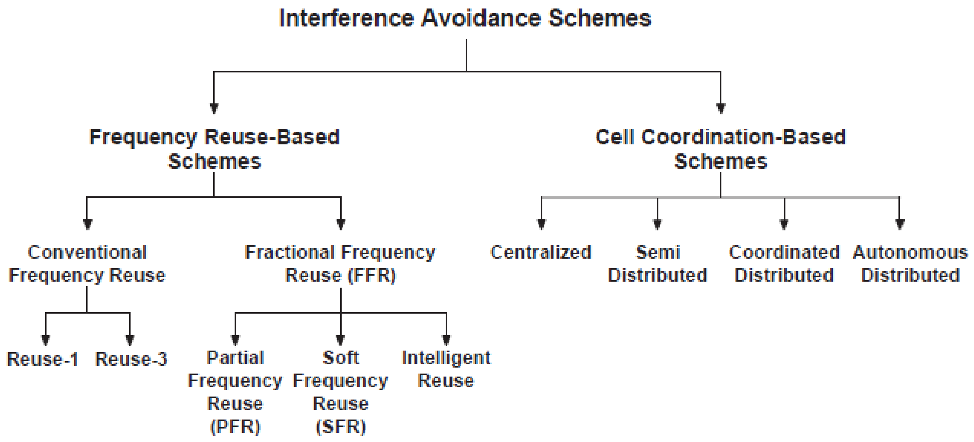


Figure 2: Interference Avoidance Schemes

2.2.1 Frequency Reuse-Based Schemes

Two schemes can be distinguished: Conventional Frequency planning schemes (Reuse-1 and Reuse-3), Fractional Frequency Reuse (FFR), partial frequency reuse (PFR), and soft frequency reuse (SFR)

2.2.2 Conventional Frequency Reuse

In the first mobile communication systems, a high power BTS was meant to broadcast over a large geographical area. This concept was greatly flowed in that it would serve a very limited number of users. Figure 3 shows an example of a cellular network.

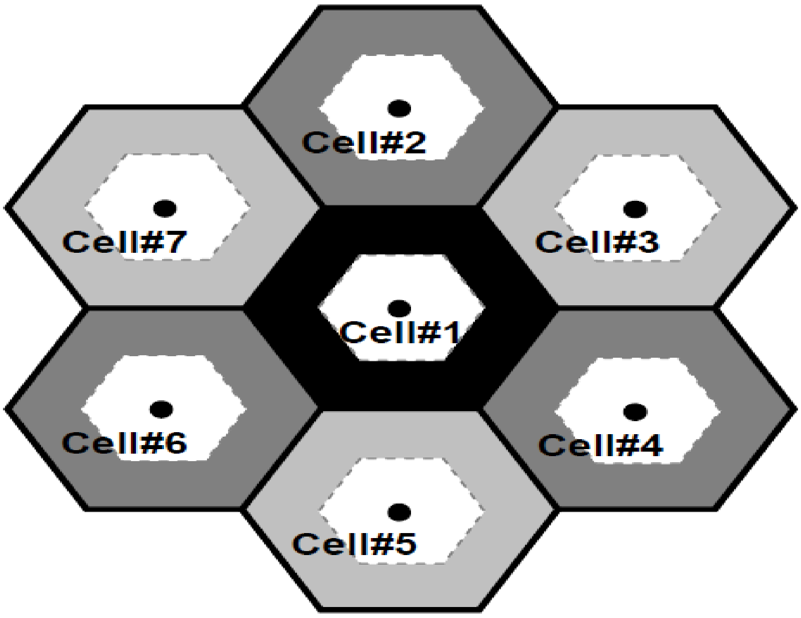


Figure 3: Cellular concept

A slightly not-so-complex method was developed to expand this coverage and also increase the number of channels (hence users) called the cellular concept. In this concept many BTSs each given a set of radio channels are utilised to cover a smaller geographical area called a channel. However if two neighbouring BTS were to use the same radio resource, there would be interference and neighbouring cells were grouped into clusters and these would have neighbouring cells using different channels. These clusters would be repeated over a larger geographical area and hence we would have the reuse of frequencies.

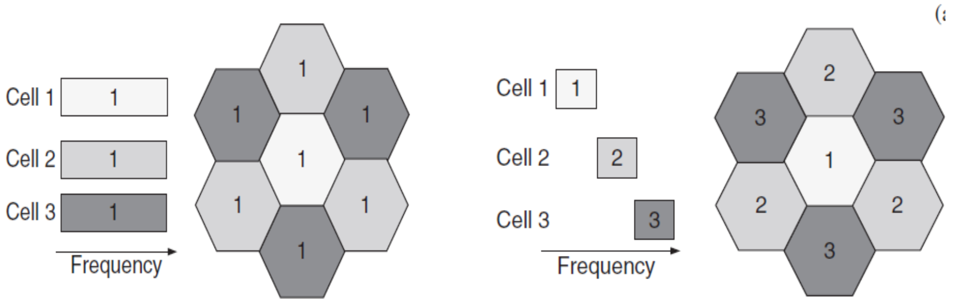


Figure 4: Frequency Reuse Schemes, with FRF=1 and 3 respectively

The easiest scheme to allocate frequencies would be using frequency reuse factor (FRF) of 1, The FRF is defined as the number of adjacent cells which cannot use the same frequencies for transmission. This makes the whole frequency spectrum available for all cell thus achieving high peak data rates but costing users especially those at cell edges with high ICI levels.

In reuse-1 adjacent cells use the same frequencies and share the whole bandwidth but must deal with the high interference from cell-edge users. Reuse-$\frac{1}{2}$ is an inter-cell interference avoidance technique that each adjacent cells are using different frequency bandwidths. Figure 4 depicts the two frequency re-use schemes where reuse 1/3 and 1 is used.

2.2.3 Fractional Frequency Reuse (FFR)

To improve the above conventional frequency reuse schemes, FFR was introduced. It effectively divides the whole available spectrum into two subgroups a major and a minor group. The former serves cell-edge users and the latter serves the cell-centre users. The following was considered:

- MSs near the cell-center not only experience high signal quality due to their close proximity to the serving BS, but are also shielded from other-cell interference due to physical separation[1].
- On the other hand, it is clear that cell-edge users will receive stronger interference from other cells, simply due to proximity. Furthermore, these

MSs will experience degraded performance due to the large distance to their BS[1].

Generally speaking, the FFR scheme can be divided into three main classes

a Partial Frequency Reuse (PFR) Schemes:

In this scheme an FRF of 1 is used for the cell-centre users and we divide the bandwidth for the cell-edge users thus cell-edge users are fully isolated from the interference from adjacent cells as they will be using different frequencies[4]. An example of partial frequency reuse is shown in figure 5.

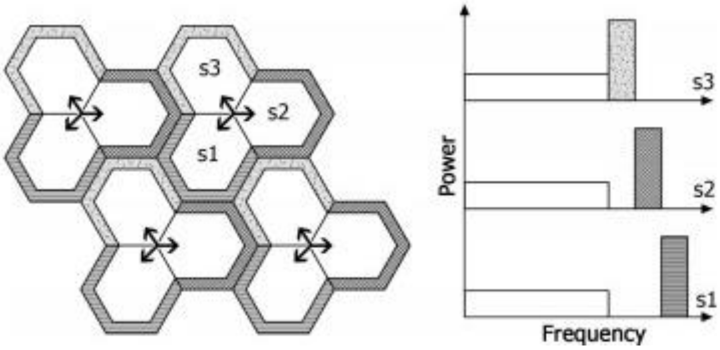


Figure 5: Partial Frequency Reuse

b Soft Frequency Reuse (SFR) Schemes:

In these schemes, each sector transmits in the whole frequency band. However, the sector uses full power in some frequency sub-bands while reduced power is used in the rest of the frequency band and thus we are controlling the power for the different regions of the cells. We allocate different levels of power to the sub bands, depending on the user location.

This particular concept is referred to as the soft frequency reuse (SFR).

A variant version of this technique is the adaptive soft frequency reuse or adaptive power control. In a network with power control capability, the transmitted power is updated based on the link quality at its receiver, e.g., SINR or bit error rate (BER).

That is in power control, the transmitter powers are constantly adjusted by increasing if the Signal to Noise Ratio (SNR) is low and decreasing if the SNR is high, so that the quality of the weak links is improved.

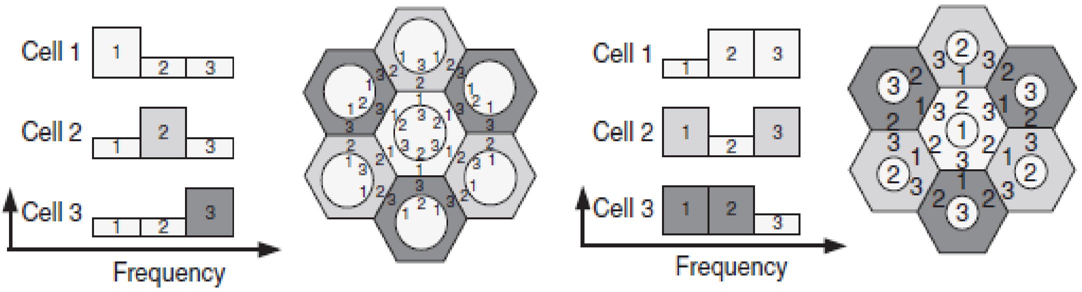


Figure 6: Soft frequency reuse:example with three sub bands[4]

In Figure 6, the whole bandwidth is divided into three sub bands. In the Figure to the left, , only one sub band is orthogonally allocated to each cell for the users at the boundary as in right Figure , while the other two sub bands are allocated to each cell for those in the centre. In order not to incur significant interference to the users at the boundaries of the neighbouring cells, the users in the inner region must use those two sub bands with lower power. Unlike the case in right Figure, entire frequency bands can be fully reused in all cells, that is, achieving FRF=1. In fact, the full frequency reuse can be enabled by allocating a lower power level to the centre users. Dividing the whole bandwidth into nine sub bands, six sub bands with lower power are allocated to the users in the inner region and the remaining three sub bands with higher power are allocated to the users at the cell boundary. The essence of the soft frequency reuse schemes is to achieve a full frequency reuse, FRF=1 while reducing the inter-cell interference at the cell boundary of the cellular communication systems.

c Intelligent Reuse Schemes:

In these schemes, band allocated to different sectors expands and dilates based on the existing workloads. These schemes start with a reuse-3 like configuration at low workloads which can be changed with the increase of workloads to become PFR, SFR or even reuse-1[2].

2.2.4 Dynamic ICIC: Cell Coordination-based Schemes

Schemes under this category can be classified along several orthogonal dimensions to mainly differentiate between static versus dynamic, and centralized versus distributed techniques. Moreover, avoidance schemes differ with respect to the resources that are being allocated/ coordinated between users, and whether various power levels need to be used at different locations in the cell.

a Static Schemes

In Static allocation schemes the resources allocated to each cell and users' class are computed and evaluated during the radio planning process and only long-term readjustments are performed during the operation of the network[2]. Thus, the set of sub-carriers and the power levels allocated to each cell and user classed (i.e. static). Static allocation schemes are relatively easy to implement as they require no frequent interaction among involved base stations. However, since it is based on static frequency reuse, once this allocation scheme is used, it is not easy to perform modifications to the major frequency distributions.

b Dynamic Schemes

In Modern mobile communication, systems have become so complex with the realization of the ‘connect, anytime, anywhere’ and the subsequent increase in the demand for bandwidth. Thus the concentration of users at different points in time is dynamic that is users at cell-edges or cell-centres. For instance we have varying concentrations of users at different times at train able to adapt to different network conditions, user traffic load, and user distribution in order to maximize on the total network throughput. Dynamic-Cell coordination schemes have emerged as an efficient solution to cope with the continuous dynamic traffic load changes in cells. In dynamic-cell coordination, interference reduction is realized by real time coordination using adaptive algorithms to efficiently manage the resource utilization among cells without prior resource partitioning.

Dynamic-Coordination-based schemes can be categorized, based on the level of coordination, into four main categorizes: centralized, semi-distributed, coordinated-distributed, and autonomous-distributed.

2.2.5 Centralized Schemes

In centralized schemes, a central control unit collects all the channel state information (CSI) of every MS in the system and allocates available frequency channel to each MS trying to maximize the capacity according to fairness and power constraints[2].

2.2.6 Semi-Distributed Schemes

As the name suggests, semi-distributed schemes are neither fully centralized nor fully distributed. Coordination in these schemes is typically performed at two levels: the central entity level and the MS level. Similar to centralized schemes, semi-distributed schemes implement a central controlling entity that controls a number of MSs. However, semi-distributed schemes, each BS is responsible for allocating channels on the frame level to the MSs that it serves.

2.2.7 Coordinated-Distributed Schemes

In coordinated distributed schemes, resource allocation is performed only at the MS level, without the need of a central entity to perform the coordination[2]. However, coordination is still needed between MSs to exchange CQI reports in order to perform global ICIC. Such coordination must be taken into consideration when designing coordinated distributed schemes, especially in very fast fading environments.

2.2.8 Autonomous-Distributed Schemes

Similar to coordinated-distributed schemes, resource allocation in autonomous distributed schemes is performed only at the MS level, with no use of a central entity for coordination. Unlike coordinated-distributed schemes; however, autonomous distributed schemes require no coordination among MSs.

2.3 Inter-cell Interference Mitigation Techniques

In interference mitigation, techniques are employed to reduce the impact of interference during the transmission or after the reception of the signal. Interference mitigation techniques include : (1) Interference randomization[5], where some cell-specific scrambling, interleaving, or frequency-hopping (spread spectrum) , (2) interference cancelation[5]: where the interference signals are detected and subtracted from the desired received signal, or if multiple antenna system is employed, the receiver can select the best quality signal among the various received signals , (3) adaptive beamforming[2]: where the antenna can dynamically change its radiation pattern depending on the interference levels.

2.3.1 Interference Randomization

This method involves randomizing the interfering technique such that the probability of interference on a communication channel is spread over all the communication channels such that not a single communication channel will always suffer interference. Techniques used are; cell-specific scrambling, interleaving, or frequency-hopping (spread spectrum)[4].

a Cell-specific scrambling

As long as intra-cell and inter-cell synchronization can be maintained in cellular systems, each sub channel can be considered independent due to the orthogonality among subcarriers. However, the interferences from adjacent cells may cause significant performance degradation; therefore, the interference signal can be randomized for enabling the averaging effect of the inter-cell interference[4]. More specifically, a cell-specific scrambling code or cell-specific interleaver can be used for randomizing the interference signal.

The figure 7 shows a block diagram of the cell-specific scrambling technique. In this technique, the transmitted signal from each cell is multiplied by the scrambling code that is uniquely assigned to the cell. The signal may have been encoded and interleaved by a FEC block. By multiplying the received signal with the same scrambling code as the one in the transmitter, the cell-specific scrambling technique allows us to whiten the interferences from adjacent cells in unicast transmission.

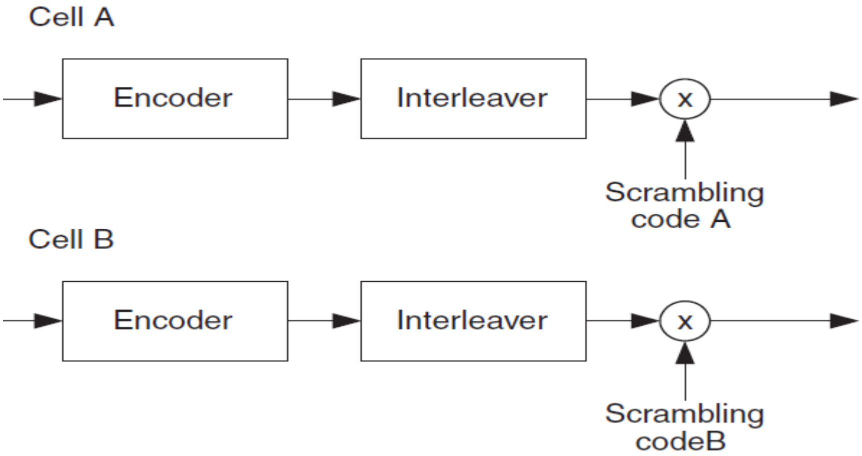


Figure 7: Cell-specific scrambling technique[4].

b Cell-Specific Interleaving

A cell-specific interleaving technique is often referred to as Interleaved Division Multiple Access (IDMA) technique[4]. The IDMA technique is similar to the cell-specific scrambling technique for the case of single-user detection, in that it whitens the interferences from adjacent cells. The IDMA technique whitens the inter-cell interference by using a specific interleaver at each cell, while the cell-specific scrambling technique performs the same job by using a specific scrambling code. Especially when the multi-user detection technique is employed in IDMA, it can reduce inter-cell interference more effectively than the cell-specific scrambling technique, by canceling interference iteratively with multiuser detector. The following figure 8 shows an example of a cell-specific interleaving technique applied to a downlink of the cellular-based cellular system, in which we assume that MS1 in BS1 and MS2 in BS 2 share the same sub channel. BS1 and BS2 use interleaver pattern 1 and interleaver pattern 2, respectively. Each MS decodes the signal by using its own interleaver pattern of the serving BS. In this case, the interference from adjacent BSs can be approximated by AWGN.

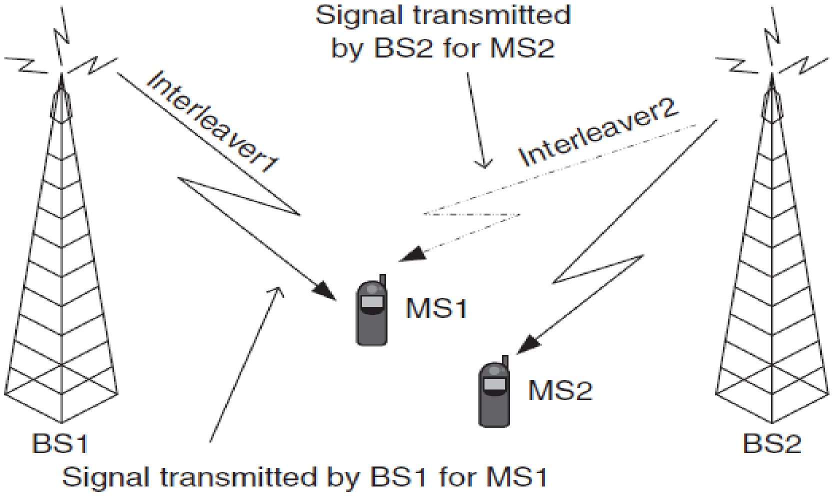


Figure 8: Cell-specific interleaving technique[4].

c Frequency Hopping

In the cellular communication system, frequency hopping (FH) is a useful technique to average out inter-cell interferences when a different hopping pattern is used for each cell[4]. In other words, it can randomize the collision between the sub bands that are used in all adjacent cells. It is referred to as a frequency hopping technique. From an implementation viewpoint, FH technique usually requires a large memory, since all the data over a period of the hopping pattern should be buffered for decoding at the receiver.

2.4 Inter-Cell Interference Cancellation Technique

In order to cancel interferences from adjacent cells, we need to detect the interfering signals first and cancel them from the received signal[6]. It is usually difficult to detect the interfering signals from adjacent cells in a practical situation.

However, spatial characteristics can be used to suppress interference when multiple antennas are available at the receiver.

2.4.1 **MIMO**

One technique is to take spatial suppression at the MS side by means of multiple antennas, MIMO and the BTS will take the antenna with the highest value of SNR[6]. A channel may be affected by fading and this will impact the signal to noise ratio. In turn this will impact the error rate, assuming digital data is being transmitted. The principle of diversity is to provide the receiver with multiple versions of the same signal. If these can be made to be affected in different ways by the signal path, the probability that they will all be affected at the same time is considerably reduced. Accordingly, diversity helps to stabilize a link and improves performance, reducing error rate[7].

Several different diversity modes are available and provide a number of advantages:

- ***Time diversity:*** Using time diversity, a message may be transmitted at different times, e.g. using different timeslots and channel coding[7].
- ***Frequency diversity:*** This form of diversity uses different frequencies. It may be in the form of using different channels, or technologies such as spread spectrum / OFDM[7].
- ***Space diversity:*** Space diversity used in the broadest sense of the definition is used as the basis for MIMO. It uses antennas located in different positions to take advantage of the different radio paths that exist in a typical terrestrial environment[7].

MIMO is effectively a radio antenna technology as it uses multiple antennas at the transmitter and receiver to enable a variety of signal paths to carry the data, choosing separate paths for each antenna to enable multiple signal paths to be used.

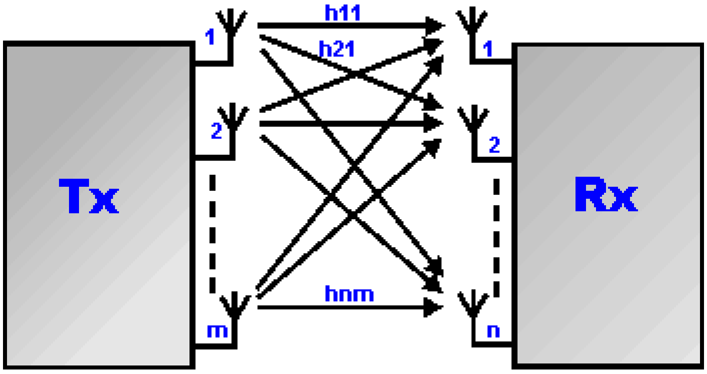


Figure 9: General Layout of MIMO[7]

2.4.2 **Beamforming**

A promising technique is the use of beamforming to concentrate the radiation from a BTS straight to a MS as explained below.

We shall go into detail on the technique that employs the usage beam forming in spatial diversity as shown in the figure 10.

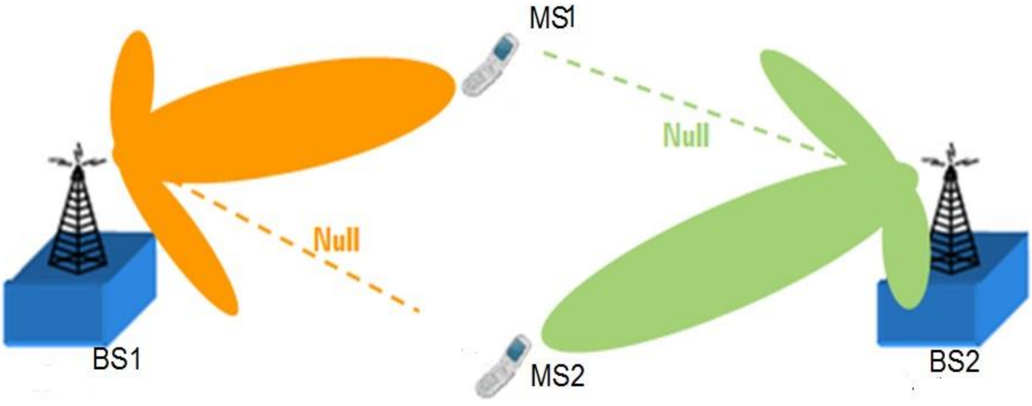


Figure 10: Beamforming towards a particular MS

A fancy term for this technique would be Space Division Multiple Access[8]. By implementing this technique at the BTS, the BTS can change the shapes of the antenna radiation according to the location of the MS and avoid interference and unnecessary leakages of power[9]. The co-channel interference and reception of excess multipath fading from undesired directions are reduced at base station, because it can issue high antenna gain in the desired direction and low gain in the undesired one. As a result, the system capacity and the quality of service improves at both the BTS and the desired MS.

In a way the BTS has to be able to regulate the beamwidth of the signal that it is transmitting to the MS in such a way so as to prevent interference. With power control the energy transmitted is regulated as a function of the level of SINR and the channel quality

The ratio of the desired signal(Carrier) power to total co-channel interference signal power(CIR) are the key parameters used to determine the capacity in mobile communication systems[10]. Because beam forming technique can greatly suppress interference, it is a powerful tool to improving the system capacity i.e. the CIR.

Beamwidth: It's the width of the radiated power in relation to the angle, Beam width is usually expressed in degrees. Beamwidth is normally measured at the half-power or -3 dB point of the main lobe unless otherwise specified[11]

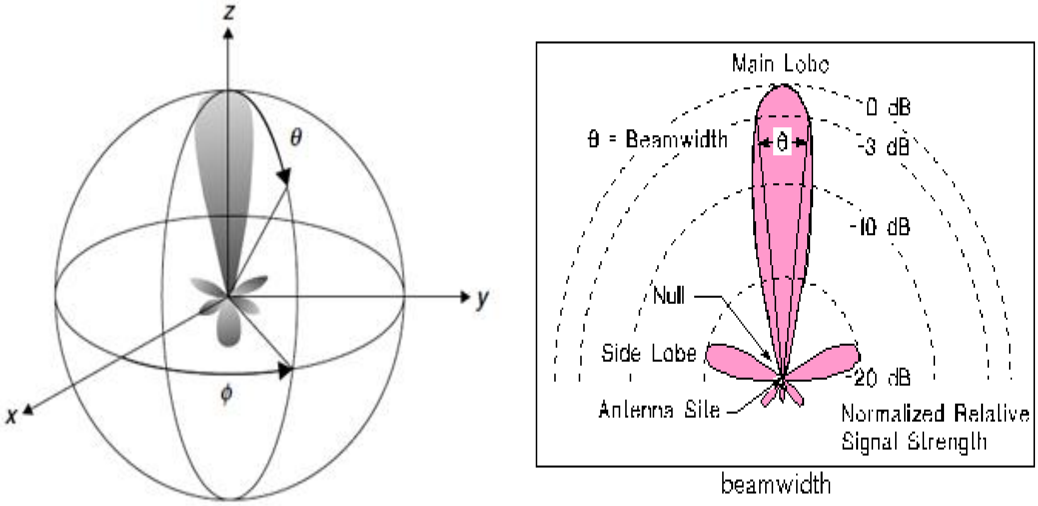


Figure 11: An antenna pattern in a spherical coordinate system

In a radio antenna pattern, the half power beam width is the angle between the half-power (-3 dB) points of the main lobe, when referenced to the peak effective radiated power of the main lobe. Figure 11 shows us an example of the antenna pattern in a spherical coordinate system.

2.5 Summary

In this chapter we have presented the problem of inter-cell interference. A brief introduction to the cellular concept is given. A summary of inter-cell interference mitigation and avoidance techniques is also provided. The beamforming technique as an inter-cell cancellation technique is discussed to facilitate the comprehension of the following chapter.

Chapter 3 Simulation

3.1 Introduction

This chapter provides an in-depth description of the system environment and performance metrics utilised throughout this thesis. This work concentrates on inter cell interference cancellation problem, therefore a multi cell network with 19 BTSs and 19 MSs are simulated. The beamforming technique is exploited in an uplink scenario in order to enhance the CIR.

3.2 Problem description

The performance of contemporary multicellular wireless networks is limited by other cell interference, due to cochannel transmission in other cells[2]. This performance degradation is especially severe for users close to the cell edge[2]. The MIMO transmission theoretically provides significant throughput gain, but the ICI is an even more complex obstacle due to the increased number of interfering sources. Many approaches that reuse the communication resources in time, frequency and/or space domain, have been proposed to this end[4]. Among these approaches smart antennas that exploit the spatial diversity of the mobile, are emerging as one of the most promising solutions.

The overall setup is an uplink scenario in which the base stations are equipped with multiple antennas and the remote receivers are equipped with a single antenna each. Within each cell, multiple remote users may be active simultaneously.

Figure 12 shows the cell layout employed in our simulation.

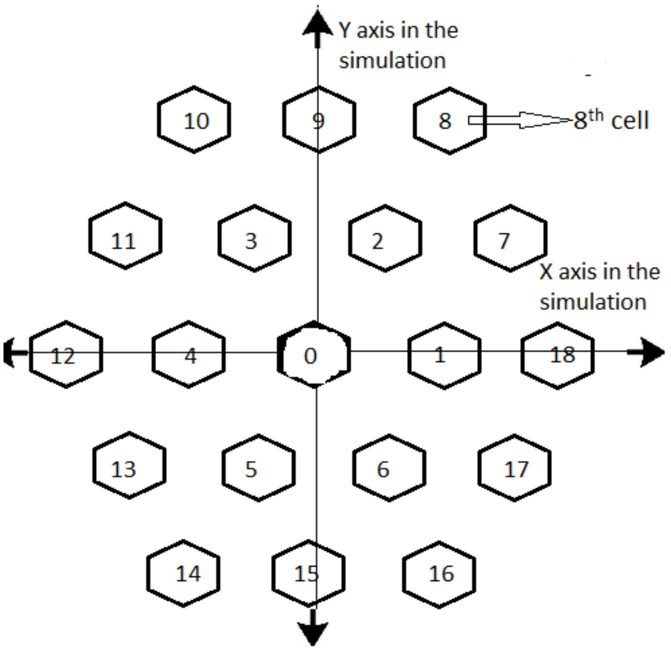
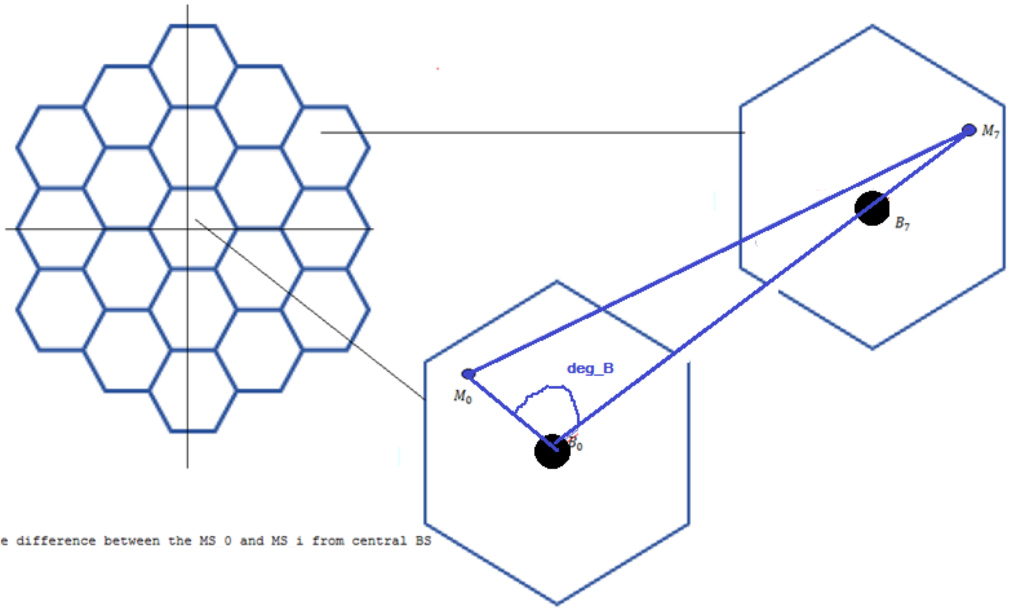


Figure 12: Cell arrangement in the simulation

It is assumed that there are 19 hexagonal cell having the cell radius of 1. The MSs are scattered randomly in each cell at each simulation. The base stations positions are stored in19*2 matrix (baseinfo). For example, « baseinfo (5, 1) » and « baseinfo (5,2) » respectively are x and y coordinates of the fifth base stations. Table 1 describes the considered network parameters.

3.2.1 System and model channel

We consider two adjacent cells; one central cell with base station B_0 and one randomly distributed Mobile Station, M_0, and an arbitrary adjacent cell with base station B_i and a mobile station M_i. In this simulation, we assume for the first case that both base stations and mobile stations are omni directional. And for the second case we consider a multiple antenna in the central base station so a beamforming technique can be applied and an omni directional antenna MS. The following figure 13 depicts this case:



deg B =angle difference between the MS 0 and MS i from central BS

Figure 13: Central base station M_i and B_i

We are considering the uplink channel between the MSs and the central BTS and calculate the CIR at the central BTS, B_0 receiving an UP signal fromM_0 and the rest of BTS and MS giving the interfering signals.

We will use the rand function in MATLAB to randomly generate the MS at each simulation as we are dealing with a case of mobile stations which are in a constant state of mobility. We will analyse the performance benchmarks that have been used in the previous chapters. We will measure the CIR at the central BTS hence we are taking into account an UP, receiving information from MSs in a cellular network. It's important that we try and create a realistic received signal. Hence the transmitted wave has to be submitted to attenuation caused by such factors as distance and obstruction hence we will introduce path loss and shadowing as attenuation factors. We will also assume that the signal being transmitted is subject to a path loss with decay factor, α=3.5 which is provided as alpha in the simulation. This will help us to calculate the path loss with the dist.m function.

Shadowing is also assumed to be a log-normal distribution with standard deviation sigma, σ which is assumed to be 6.5 in the simulation. Table 1 summarizes the parameters used in the simulation.

Table 1: Network parameters

Parameters	**Values**
Cellular Layout	hexagonal
transmission interface	Air
Number of MSs	19
Number of BTSs	19
Number of cells sharing same frequency	19
α	3.5
σ	6.5
Number of MSs interfering at central BTS	18

The network can have any cluster size but the idea in this simulation is having 19 cells having the same frequencies that have MSs interfering with the UP signal from the M_0 to B_0 .

3.3 Simulation

3.3.1 Inter Cell Interference Cancellation algorithm description

1. Define the positions of the base stations.
2. Distribute randomly the mobile stations in each cell.
3. Choose arbitrary mobile station from each cell.
4. Calculate the distance and the angle between a chosen mobile station in the i^{th} cell and its correspondent i^{th}base station.
5. Calculate the distance and the angle between a chosen mobile station in the i^{th} cell and the central base station.

6. Case 1: using beamforming

Assigns transmission power of MS, Power_MSi=70dB

for each MS_i ***do***

I. calculate the horizontal and vertical angle differences between the M_0 and M_i from B_0 (***degHBS, degVBS***)

II. Calculate n for $\theta = 0:360$

$$n = \frac{\log_{10}\left(\sqrt{\frac{1}{2}}\right)}{\log_{10}(\cos(\frac{\theta\pi}{180}))} \text{ [10]}$$

III. Calculate the antenna gains: GHBs, GVBS, GHMS, GVMS as given by the following equations:

$$G_{HB}(\emptyset) = \begin{cases} 10\log_{10} cos^{n}\emptyset & \frac{-\pi}{2} \leq \emptyset \leq \frac{\pi}{2} \\ 0 & otherwise \end{cases} \text{ [10]}$$

IV. Calculate the effect of the shadowing,

$$shadowing = 10^{0.1\times\alpha\times Var} \text{ [10]}$$

$$\alpha = 3.5$$

V. Calculate the propagation Loss from each M_i

$$Loss = 10log_{10}d^{-\alpha}$$

7. Calculate CIR

Case 1: With Beamforming.

$$CI\_dB = power\_M_i + GHBs(degHBS) + GVBS(degVBS) - loss - shadow.$$

$$CIR = \frac{CI(M_0)}{CI(all\ M_i)}$$

$power\_M_i$ is the transmission power at M_i.

$GHBs$ is the horizontal antenna gain of B_i.

$GVBS$ is the vertical antenna gain of B_i.

$GHMS$ is the horizontal antenna gain of M_i.

$GVMS$ is the vertical antenna gain of M_i.

$degVBS$ is the angle difference in vertical direction between M_i and B_0

$degVMS = degVBS$.

Case 2: without beamforming

$$CI\_dB = power\_M_i - loss - shadow.$$

$$CIR = \frac{CI(M_0)}{CI(all\ M_i)}$$

3.3.2 Overview of terms used in the simulation

a Cluster Size

Figure 15 shows how we determine the distance between base stations in this work and in figure 14 we have cells using the same frequencies or co-channel marked with the same colour, if we take for instance the cell in purple, for us to move to the closest co-channel we need to move two cells up, thus i=2 and another cell to the right, j=1, with this information we can get the cell cluster size, n.

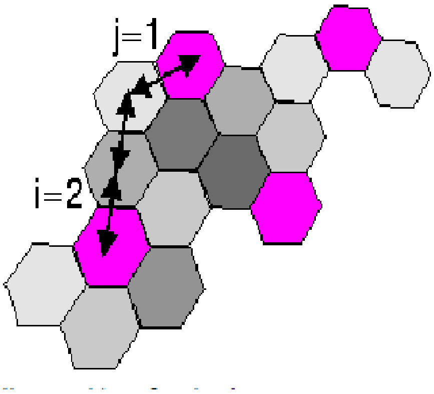


Figure 14: Co-ordinate positioning for cells

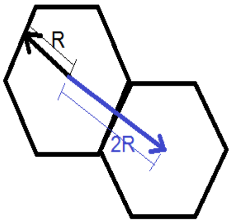


Figure 15: Cell radius and coverage

The regular repetition of frequencies results in a clustering of cells. Cluster of cells n is defined as a group of adjacent cells which use all of the systems frequency assignment and no frequency reuse exists amongst them[12]. The clusters generated in this way can comprise the whole frequency band, in this case all of the frequencies in the available spectrum are used within a cluster, the size of a cluster is characterized by the number of cells per cluster n, which determines the frequency reuse distance D.

$$n = i^2 + i * j + j^2 \text{ [12]}$$

b Antenna Gain

Antenna gain, the term Antenna Gain describes how much power is transmitted in the direction of peak radiation to that of an isotropic source. Antenna gain is more commonly quoted in a real antenna's specification sheet because it takes into account the actual losses that occur[13].

An antenna with a gain of 3 dB means that the power received far from the antenna will be 3 dB higher (twice as much) than what would be received from a lossless isotropic antenna with the same input power[14].

The main program sets the values for the standard deviation of shadowing and the path loss to be 6.5 and 3.5 respectively. Similarly it assigns the following values for the beam width at BS for target direction in degrees, antenna gain at BS for the opposite direction in dB, beam width at the BS in degrees.

This coefficient is used in the calculation of the gain:

$$n = \frac{\log_{10}\left(\sqrt{\frac{1}{2}}\right)}{\log_{10}(\cos(\frac{\theta\pi}{180}))} \text{ [10]}$$

We determine the characteristics of the antenna gain at both the BS and the MS. Hence we define BS of the *i*th cell as B_i. We also define the *i*th cell as M_i.

$$G_{HB}(\emptyset) = \begin{cases} 10\log_{10}(\cos\emptyset)^n & \frac{-\pi}{2} \le \emptyset \le \frac{\pi}{2} \\ x & otherwise \end{cases} \text{ [10]}$$

$$for\ \theta = (1{:}89), gain(\theta) = 10 * \log_{10} cos^n(\theta * \frac{\pi}{180}))dB \text{ [10]}$$

$$for\ \theta = (272{:}360), gain(\theta) = 10 * \log_{10}(\cos\left(\theta * \frac{\pi}{180}\right)^n)dB \text{ [10]}$$

If the value of back is approximately equal to null, which gives us the value of the antenna gain in the horizontal direction,

$$for\ \theta = (90{:}271), gain = back\text{[10]}$$

c Path loss

The received power decreases when the length between the transmitter and the receiver increases. This is called the propagation loss, and it decreases in proportion to γ^{α} [15] where γ the median value of received signal is in large scale and α is attenuation constant. In a normal case the value of α is 2 to 5[14]. The following figure 16 shows an example of path loss conditions in a communication channel.

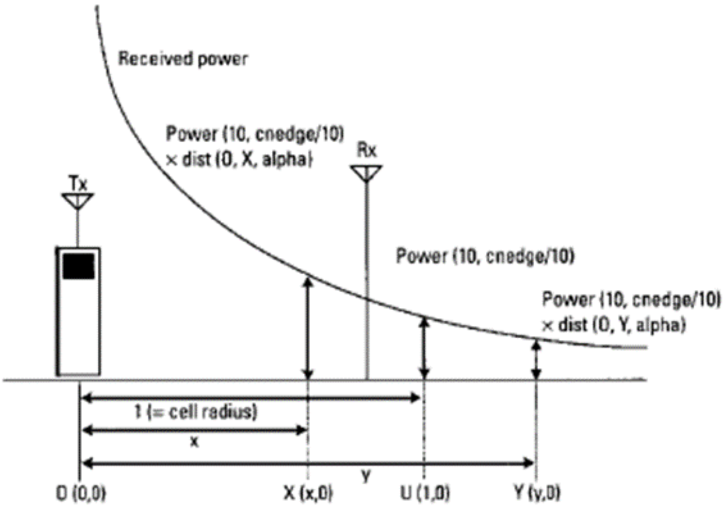


Figure 16: Path loss conditions[10]

$$\alpha(db) = 92.45 + 20\log_{10}(d) + 20\log_{10} f$$

f: is the signal frequency (in GHz)

d: is the distance between the transmitter and the receiver (in km),

We determine the distance between the M_i and B_i , this will be used to get the path loss, $d^{-\alpha}$ [10]

Propagation loss from the M_i to B_i is calculated using the formula:

$$loss = 10 * \log_{10}({d_2}^{\alpha})dB$$ [10]

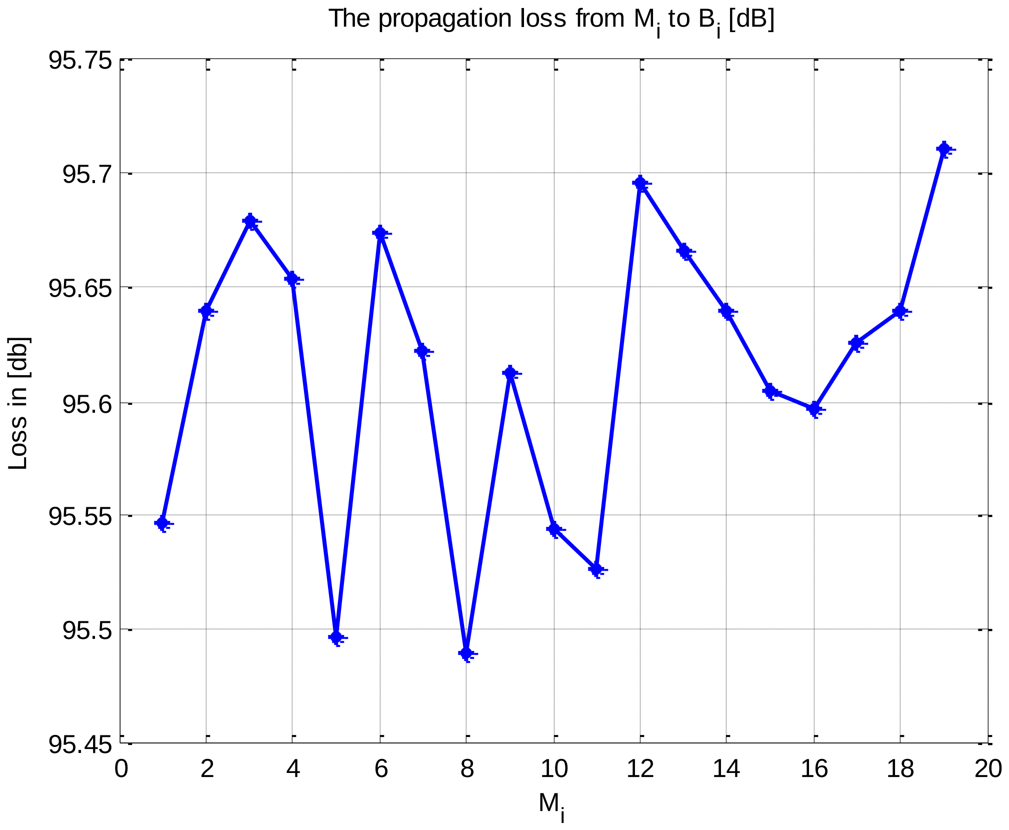


Figure 17: Propagation loss from the M_i to B_i

Propagation loss of the central BS, B_0 to M_i is calculated as follows:

$$loss = 10 * \log_{10}({d_2}^{\alpha}) dB \text{ [10]}$$

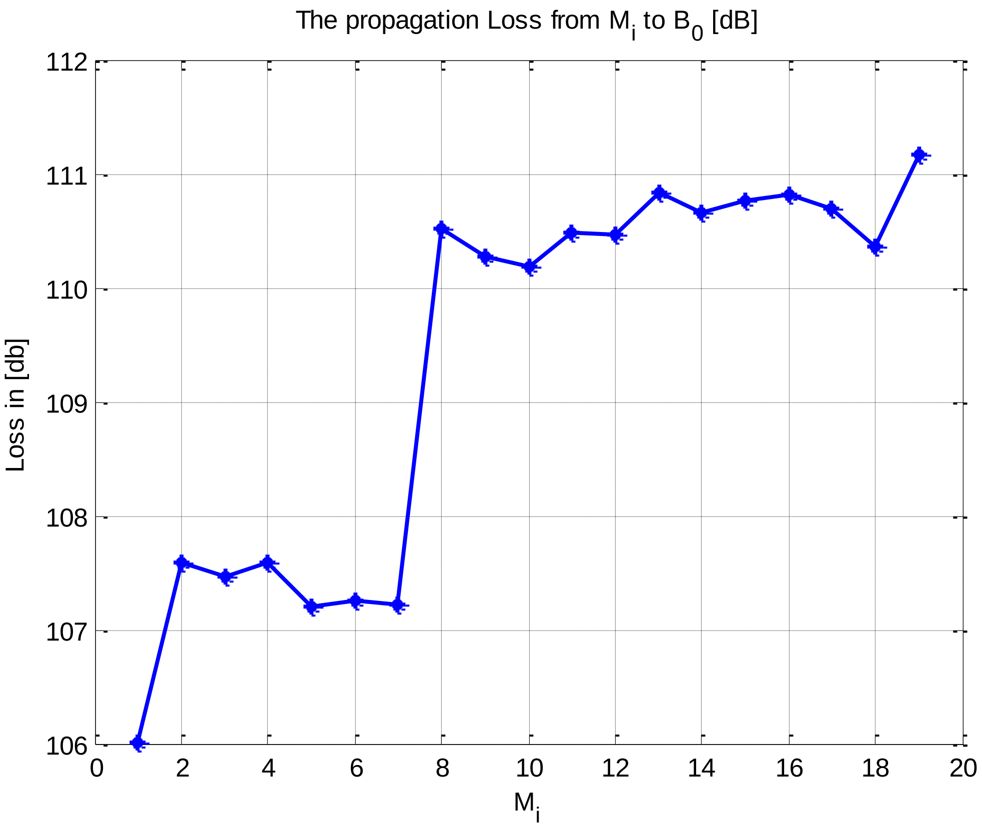


Figure 18: Propagation loss of central B_0 to M_i

Maximum loss from cell boundary to BS is calculated using the formula:

$$loss = 10 * \log_{10}(r^{\alpha}) dB \text{ [10]}$$

$d_{2:}$ distance between M_i and B_i

λ=0.1

d Shadowing

The transmission radio signal is received as a multiple radio wave that has passed through several routes by such events as reflection and diffraction. The received power intensely fluctuates by receiving the multiple radio wave. The fluctuation is called fading. The median value of the fading over several tens of wavelengths is called the median value in small scale. The median value of the median value in a small scale over several tens of wavelength is also fluctuated by obstacles and called shadowing [16]

Shadowing is calculated for each MS in the simulation, with the following figure 19 showing attenuations of 19 MS

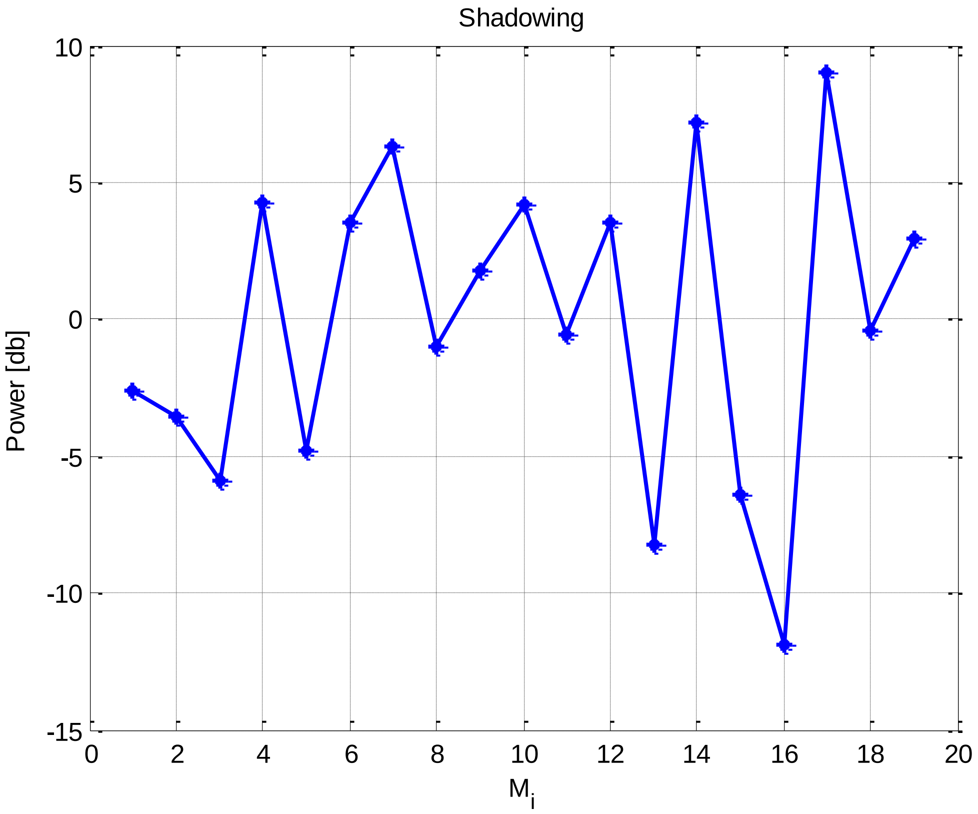


Figure 19: Shadowing undergone by M_i

e CIR

The carrier-to-Interference (C/I) ratio is the ratio, expressed in dB, between a desired carrier (C) and an interfering carrier (I) received by the same receiver, which is called the "victim" receiver[17] .

With all the results that we have obtained from the previous functions, i.e. θ_{HB}, θ_{MB}, P_i, $G_{VB}, G_{HB}, G_{HM}, G_{VM}$, we should be able to determine the total CIR in dB. Considering the central base station B_0, the ration of the power of the desired signal from M_0, to the power of interference signals from M_0 to M_i is given by the following formula:

$$CIR_{tot} = \frac{AP_o{}^{-\alpha} P 10^{\frac{\sigma_0}{10}} \times 10^{\frac{G_{HB_0}(\theta_{HM_0})}{10}} \times 10^{\frac{G_{VB_0}(\theta_{VM_0})}{10}} \times 10^{\frac{G_{HM_0}(\theta_{HB_0})}{10}} \times 10^{\frac{G_{VM_0}(\theta_{VB_0})}{10}}}{\sum_{i=1}^{18} AP_i d_i{}^{-\alpha} 10^{\frac{\sigma_i}{10}} \times 10^{\frac{G_{HB_0}(\theta_{HM_i})}{10}} \times 10^{\frac{G_{VB_0}(\theta_{VM_i})}{10}} \times 10^{\frac{G_{HM_0}(\theta_{HB_i})}{10}} \times 10^{\frac{G_{VM_0}(\theta_{VB_i})}{10}}} \text{ [10]}$$

A is a proportional coefficient.

P_i is the transmission power at M_i.

d_i is the distance between B_0 and M_i.

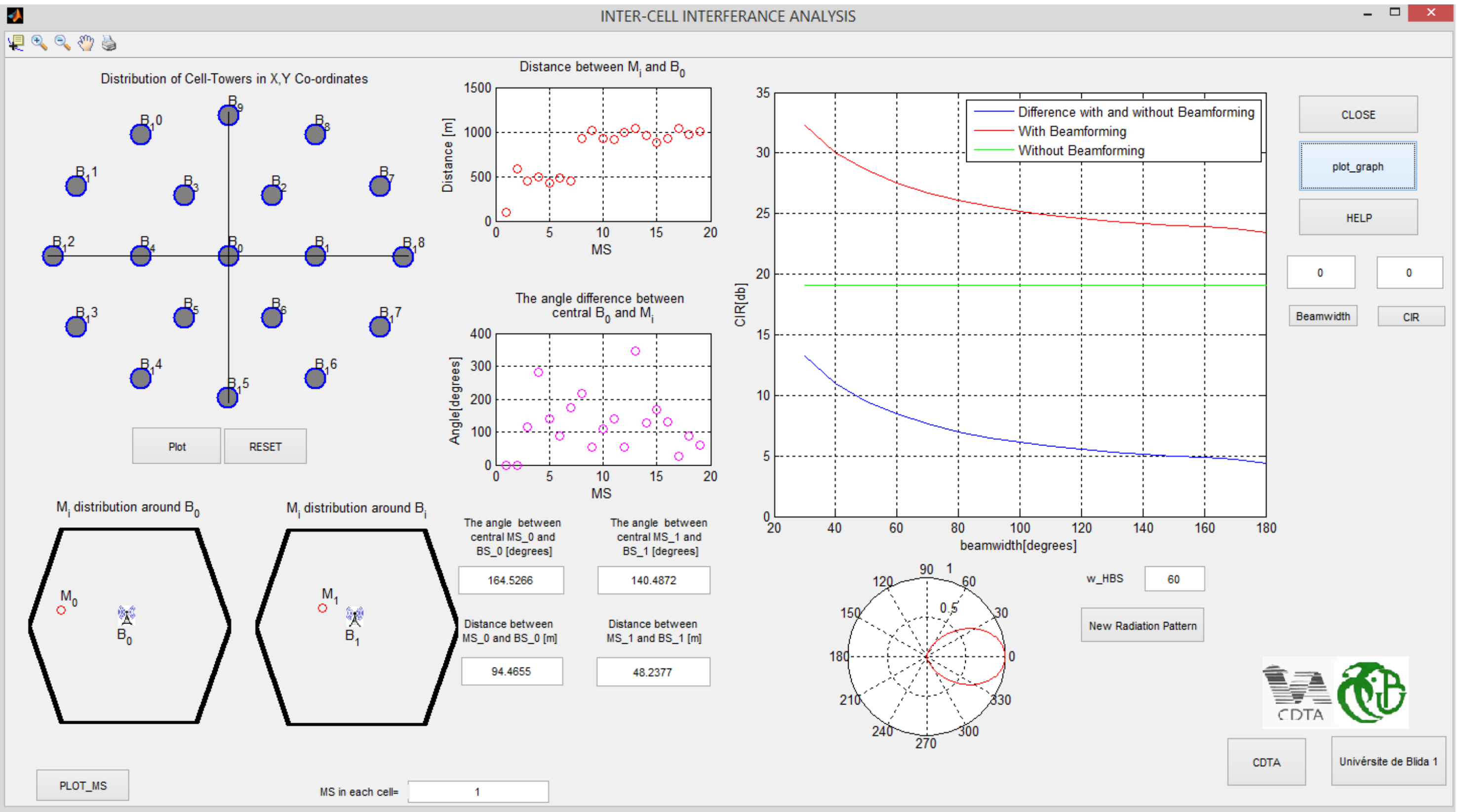
σ_i is the distortion due to shadowing.

3.4 Simulations and Results

The implementation of a graphical user interface most importantly requires fundamental knowledge of the subject being addressed. Secondary to this is the requirement that the overall model will be understood. The fundamental knowledge for the inter-cell interference cancelation is presented and discussed in chapter 2, and discussions on the overall considered cellular system were presented previously.

3.4.1 Graphical User Interface Manipulation

The GUI helps the operator to feed the simulation with the relevant data (user distribution, network configuration and parameters) and prepares the simulation results in diagrams and plots. The working surface is shown in figure 20.



The angle between central MS_0 and BS_0 [degrees] 164.5266

The angle between central MS_1 and BS_1 [degrees] 140.4872

Distance between MS_0 and BS_0 [m] 94.4655

Distance between MS_1 and BS_1 [m] 48.2377

w_HBS 60

MS in each cell= 1

Figure 20: GUI

3.4.2 **Components of GUI**

As seen in figure 20, the default view of the main screen for this GUI concept is divided into several panels. These are:

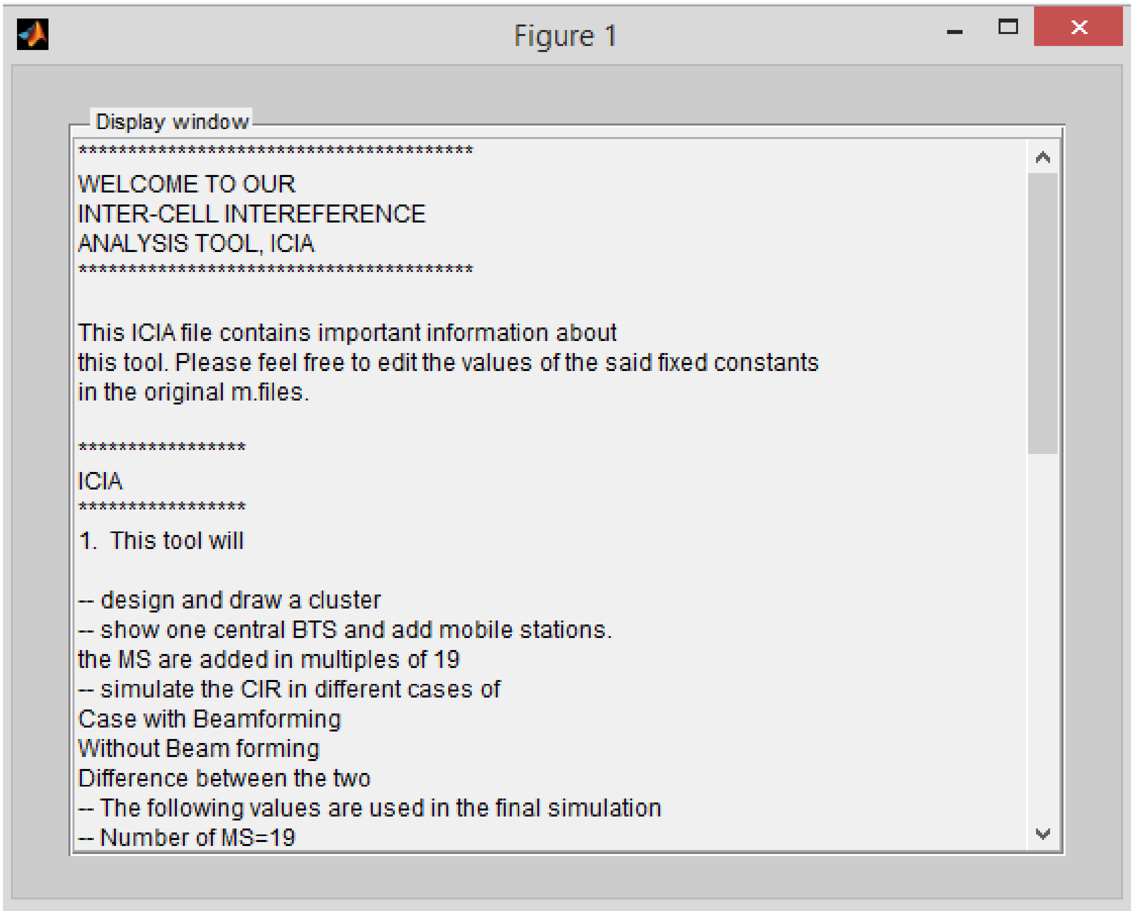
1. Entries
2. Base stations distribution
3. Mobile stations locations
4. Radiation beam pattern
5. CIR curves

1. Entries

A screenshot of the entries is available on figure 26, the user can specify the beam width, and arbitrary Mobile station locations. This leads to calculate both distances between Mobile stations and Base station in the aim of calculating path losses. Also, it allows calculating angle differences between mobile stations and Base station in order to estimate the required antenna gain. One can also specify the beamwidth for calculating the corresponding CIR.

3.4.3 Parameters used in the simulation

This will display a pop up window detailing all the parameters used in the simulation.



```
******************************************
WELCOME TO OUR
INTER-CELL INTEREFERENCE
ANALYSIS TOOL, ICIA
******************************************


This ICIA file contains important information about
this tool. Please feel free to edit the values of the said fixed constants
in the original m.files.

******************
ICIA
******************
1.  This tool will

-- design and draw a cluster
-- show one central BTS and add mobile stations.
the MS are added in multiples of 19
-- simulate the CIR in different cases of
Case with Beamforming
Without Beam forming
Difference between the two
-- The following values are used in the final simulation
-- Number of MS=19
```

Figure 21: HELP button pop up

3.4.4 Base Station Distribution.

A screenshot of the BTS distribution can be shown in figure 22. A cellular concept is considered in this simulation; the entire service area is divided into several small areas called cells. A base station is located in the center of each cell allocates several channels for mobile terminals within the cell. One of the most common features of the cellular system is that the same channel can be concurrently allocated in different cells if they are sufficiently spaced apart. If the same channels are allocated in closer cells, each cell causes co-channel interference to the other cells and degrades the transmission quality.

In this work, the base stations are distributed as it is shown in figure 22. The central base station is located at (x,y)=(0,0).

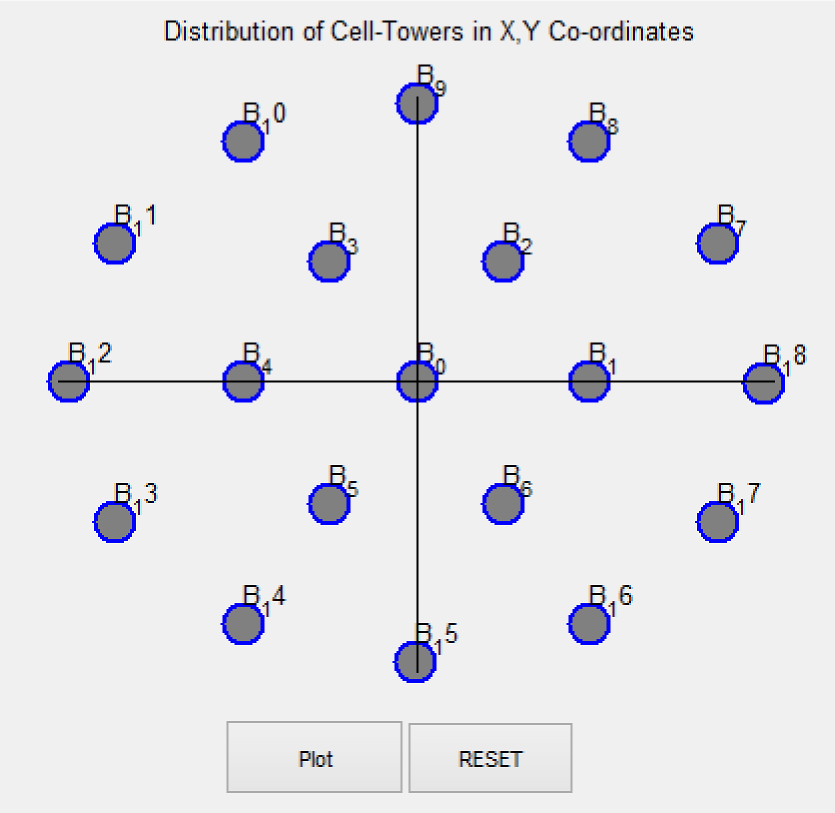


Figure 22: Distribution of B_i

3.4.5 Mobile Stations

Mobile stations positions are generated randomly in both adjacent cells used in this simulation. The figure 23 depicts an arbitrary case, where one of the 19 adjacent cell is selected. Using Plot_Ms button, a new locations for Mobile stations are generated around base station. The user can specify the number of the MS in each cell, but only one MS in each cell is considered. Figures 23, and 24 displays the exact location of the $\mathrm{M_i}$ according to the corresponding $\mathrm{B_i}$ and the $\mathrm{B_0}$ in terms of angles and distances.

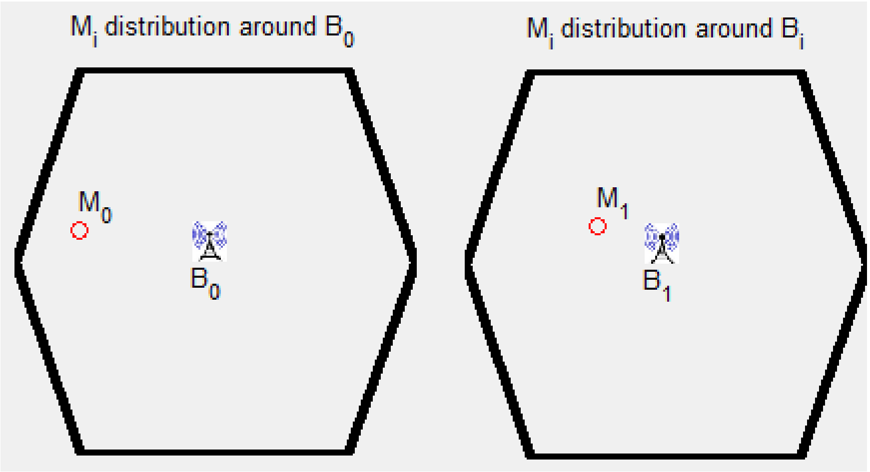
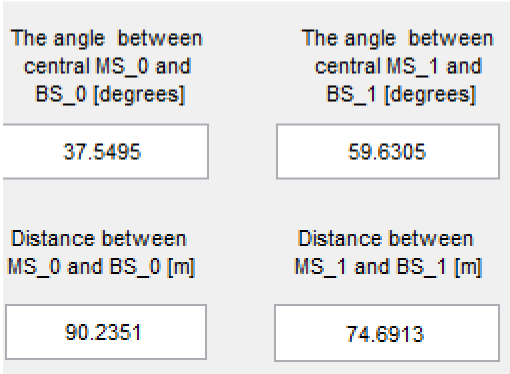


Figure 23: MS distribution in Cell-0 and Cell-1



The angle between central MS_0 and BS_0 [degrees]: 37.5495

The angle between central MS_1 and BS_1 [degrees]: 59.6305

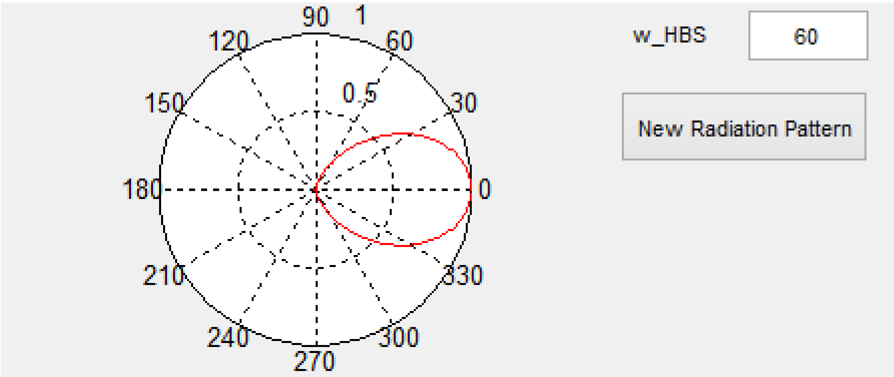
Distance between MS_0 and BS_0 [m]: 90.2351

Distance between MS_1 and BS_1 [m]: 74.6913

Figure 24: Distance and angle of M_0, M_i in relation to B_i and B_0

3.4.6 **Radiation beam pattern**

As it is shown in figure 25 a screen shot of the radiation beam pattern is available. According to the specification of the beamwidth by the user, this beam pattern can change its shape as it can be seen in figure 26.



w_HBS: 60

Figure 25: Radiation pattern

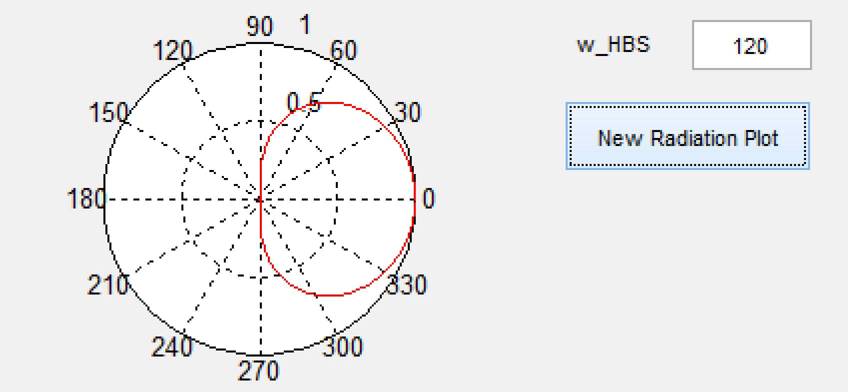


Figure 26: New radiation pattern versus beamwidth

3.4.7 CIR curve

The aim of this work is to evaluate the inter cell interference cancellation technique based on the beamforming technique. A CIR curve is drawn as it can be seen in the screenshot available in the figure 27.

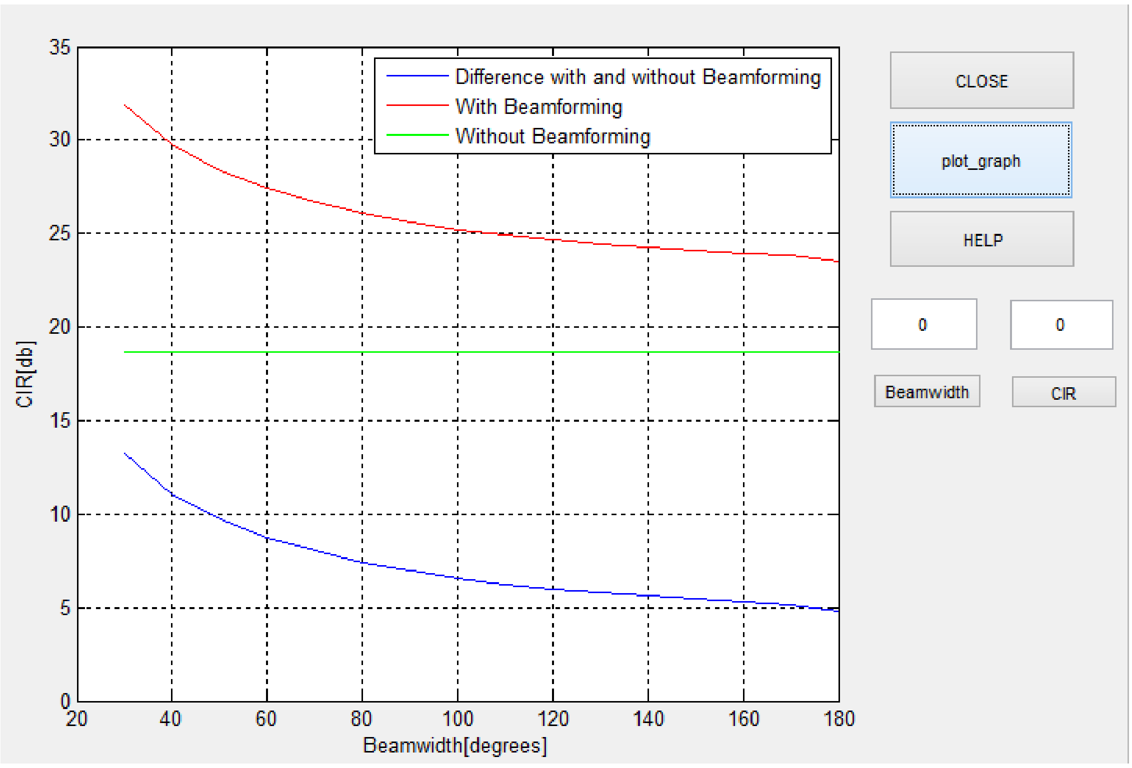


Figure 27: CIR curve

This figure 27 corresponds to the variation of the CIR versus the beamwidth at the central base station. The horizontal axis corresponds to the beamwidth at the central base station, and the vertical axis corresponds to the CIR values. Two cases are considered; using beamforming (blue curve) and without beamforming (green curve). The difference between the two curves is also drawn (red curve). The average CIR with beamformig control shows an improvement of more than 5 dB as compared to that witout beamforming.

3.4.8 Other results

a Mobile station location

This figure 28 show the angle differences between the M_0 and M_i from central B_0 and the angle difference between the B_0 and B_i from M_i for the 19 adjacent base station.

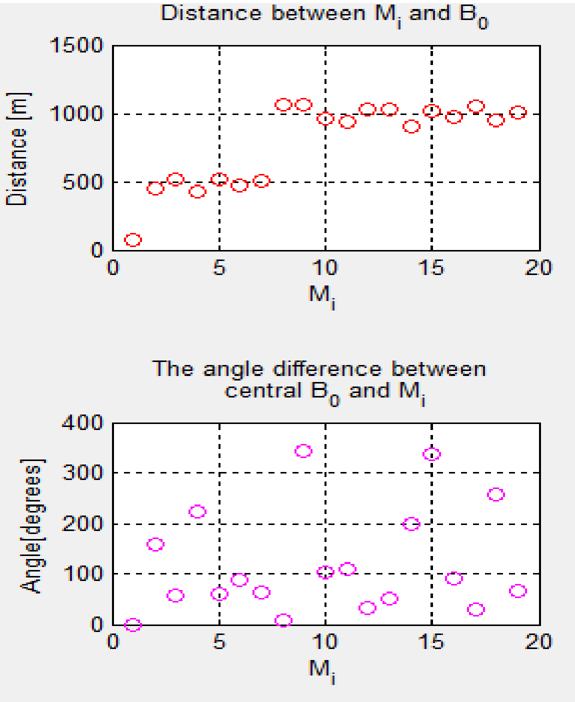
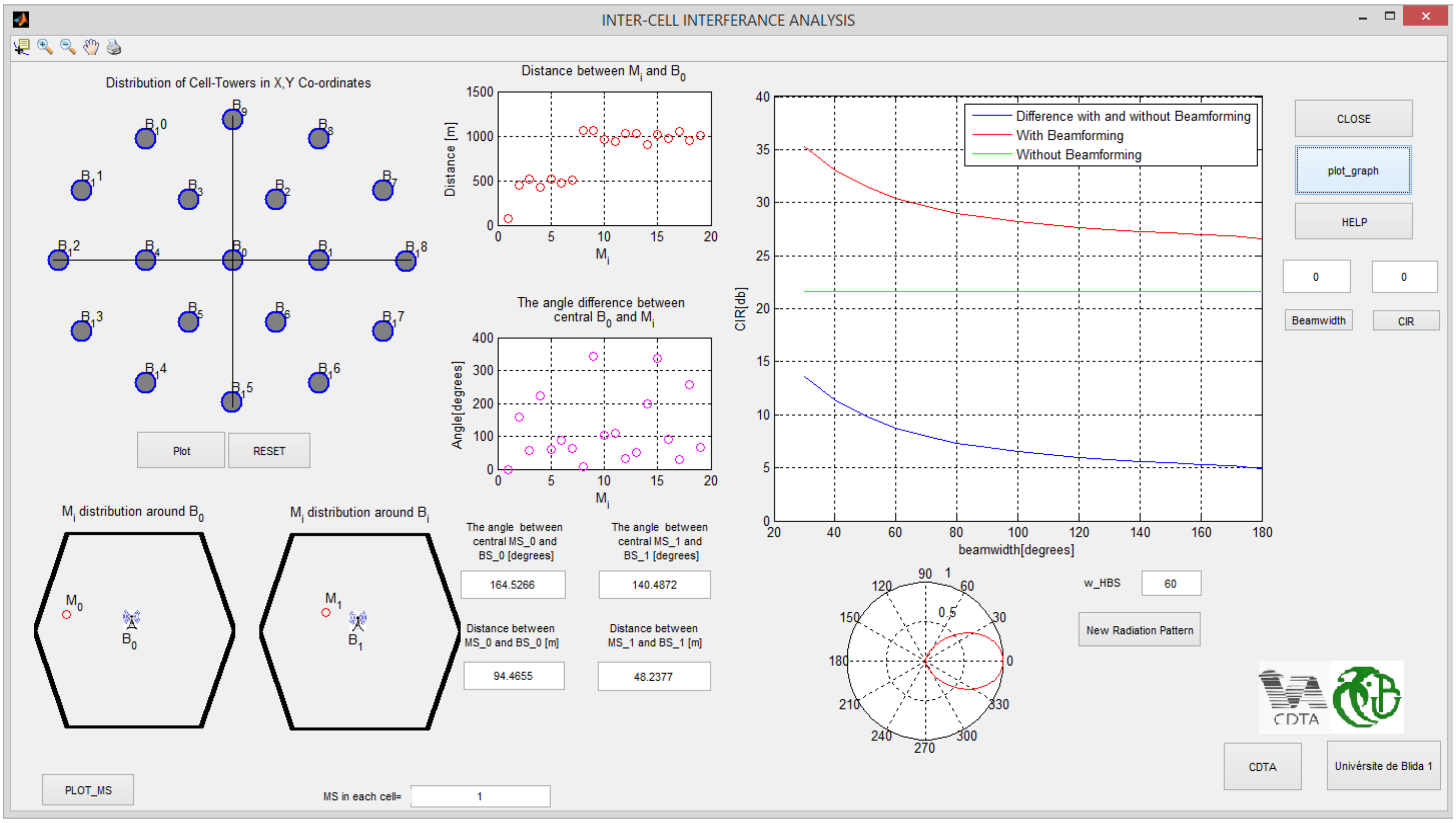


Figure 28: Distance between M_i and B_0 and angle difference between B_0 and M_i

3.4.9 Final GUI

The figure 29 shows the final appearance of the GUI.



The angle between central MS_0 and BS_0 [degrees]: 164.5266

The angle between central MS_1 and BS_1 [degrees]: 140.4872

Distance between MS_0 and BS_0 [m]: 94.4655

Distance between MS_1 and BS_1 [m]: 48.2377

w_HBS: 60

Beamwidth: 0

CIR: 0

MS in each cell= 1

Figure 29: Final GUI

3.4.10 Conclusion

In this chapter, an inter cell interference problem is treated in a cellular mobile system. The beamforming technique is exploited to cope with this problem by adjusting the radiation beam towards the desired signal. The carrier to interference ratio (CIR) has been observed as a metric and Satisfying results has been perceived at sharpen beam. In this regard, a GUI is conceived in order to allow the user feeding the simulation by relevant data (user distribution, network configuration and parameters) and display the simulation results.

General Conclusion

Inter-cell interference is a fundamental limiting factor in wireless cellular networks that occurs when the same frequency band is used for adjacent cells and worsens especially at cell edge[2]. This type of interference can be reduced by allocating different frequency bands to adjacent cells (frequency reuse), but this narrows the band that can be used by each cell[4], which reduces throughput. This is why frequency reuse is not executed in recent mobile systems, which instead use frequency-reuse 1[18].

In order to cancel interferences from adjacent cells, we need to detect the interfering signals first and cancel them from the received signal. It is usually difficult to detect the interfering signals from adjacent cells in a practical situation. However, spatial characteristics can be used to suppress interference when multiple antennas are available at the receiver.

In this work, we have investigated three main types of inter-cell interference mitigation techniques: inter-cell interference avoidance, inter-cell interference cancellation and inter-cell interference mitigation using smart antennas. The beamforming technique as an inter-cell interference mitigation technique has been discussed and simulated.

An uplink scenario has been considered in our simulation, in which the base stations are equipped with multiple antennas and the mobile stations are equipped with a single antenna each. Within each cell, multiple remote users may be active simultaneously. It is assumed that there are 19 hexagonal cell having the cell radius of 1. The Mobile stations are scattered randomly in each cell at each simulation. At a central base station equipped with multiple antennas, a beamforming technique is exploited to eliminate the signal emanating from a mobile station with omni-directional gain from adjacent cell.

In this regard, the carrier to interference ratio (CIR) as a metric has been observed by manipulating the beam width at the central base station. Satisfying results has been perceived at sharpen beam.

A MATLAB/GUI based tool has been developed in the aim of allowing the operator feeding the simulation by relevant data (user distribution, network configuration and parameters) and display the simulation results in form of diagrams and plots.

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