Interference Modelling of IMT-A Systems in Local Area TDD Scenarios

Group No. 08gr1119

Juan José García Agulló
María Luna Abad
Gemma Puig Arbat

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GROUP MEMBERS:

Juan José García Agulló
María Luna Abad
Gemma Puig Arbat

SUPERVISORS:
Troels B. Sørenssen
Yuanye Wang

Orthogonal Frequency Division Multiple Access(OFDMA) and Single Carrier Frequency Division Multiple Access(SC-FDMA), the access techniques used in DL and UL respectively in UTRAN LTE, are strong candidates also for IMT-A systems, namely $4G$. IMT-A systems are expected to provide peak-data-rates in the order of $1Gbit/s$ in Local Area(LA) and $100Mbit/s$ in wide area[2]. Such high data rates require techniques to achieve high spectral efficiency ($bits/s/Hz$) and very high spectrum allocation in the range of $100MHz$.
While Frequency Division Duplex(FDD) is extensively used in current systems, Time Division Duplex(TDD) has gradually attracted the research interests for its many advantages over the former. Network synchronization is more complicated in TDD than in FDD but this can be easily treated in local area (LA) scenarios. Therefore, the purpose of this study is to evaluate these synchronization interferences in LA.
As starting point a computer simulator from [3] will be studied and some new algorithms will be implemented in order to study the posible better performance of the target scenario. Spectrum allocation method is our goal to reduce the interference between both Base stations(BSs) and BS allocated in adjacent cells, and then Power Control(PC) method will be added also in order to improve the results by allowing the operator to manage the level of power needed by each user. Effective SIR Method (ESM) will be also implemented in the simulator in order to approach to more realistic conditions based on system-level evaluations, it allows to compare OFDMA and SC-FDMA performance and identify the most promising one under different system configurations and under different synchronization scenarios.
The starting point is the study in terms of SINR for different scenarios in order to decide which one has better performance, when cells have more than one room and squared shape instead of rectangular. For the following simulations the better SINR response scenario will be choosen in order to reach better results as posible with the new implemented methods. Then is shown that sorting approach improves UL signal for more interfered users and together with PC downlink(DL) is also improved in the same way. Finally, it is shown that implementing ESM , effective SIR, which is representative of OFDMA, performs worse than SIR in DL whereas for UL the SC-FDMA outperforms OFDMA.

Acknowledgement

We would like to express our gratitude to our supervisors Troels B. Sørensen and Yuanye Wang for their valuable guidance throughout this project and all of those people who directly or indirectly helped us to complete this project.

Contents

Chapter 1

Introduction

1.1 Introduction and motivation

A big step in communication systems has been done since the introduction of analog cellular services until the latest research about the new standards for next generation in mobile communications. Going from 1st generation (1G) until the expected 4G, the performance of communication systems has been improving with the appearance of new technologies.

Wireless has been a very important technology and has emerged rapidly in the market since it provides network mobility, scalability and connectivity to the users [11]. Wireless differs from the wired networks because it can transmit and receive the signal through the propagation medium between a client (mobile station(MS)) and an access point (base station(BS)). The radio waves can propagate through walls, floors and even more consistent structures [12].

There is a wide range of wireless devices used for communications purposes. Today, it can broadly be characterised as mobile, fixed and short-range. Therefore, this project will be focused on cellular mobile communications.

Cellular systems introduced in eighties, with the so-called analog cellular services[4]. 1G allowed cell technology to provide the users with voice call service while they move through several coverage areas belonging to different base stations. It worked with the implementation of FDM, which allocates each user in separate frequency channels. In FDM systems, signals from multiple transmitters are sended simultaneously (at the same time slot) over multiple frequencies. Each sub-carrier is modulated separately by different data stream and a spacing (guard band) is placed between sub-carriers to avoid signal overlap as shown in Figure1.1.

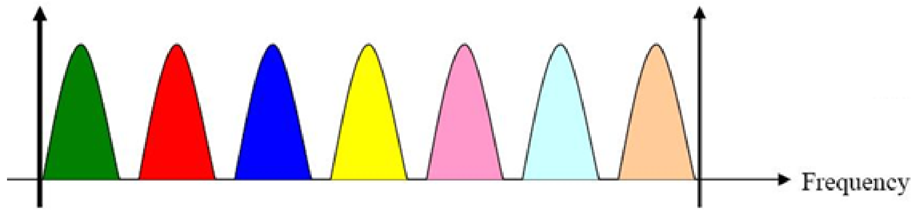

Figure 1.1: FDM: Frequency division multiplexing.

The Second-generation cellular systems (2G), appeared as a digital cellular technology, uses two different access systems in competition between them: TDMA (Time division Multiple Access) and the emerging system with Code Division Multiple Access (CDMA).

By 2006 most cellular operators had started the process of deploying a new generation of cellular systems, which is the 3G, and in some cases gradually migrating customers from their 2G networks to 3G. This promises to be a long process with 2G and 3G networks running in parallel for many years to come [1].

There is a range of technologies for 3G, all based around CDMA technology and including W-CDMA (with both FDD and TDD variants), TD-SCDMA (the Chinese standard) and Cdma2000 (the US standard). The key characteristics of 3G systems include the ability to carry video calls and video streaming material and realistic data rates extending up to 384 kbits/s in both packet and circuit switched modes [1].

Nowadays, a new cellular standard called 4G is adding new improvements to the characteristics of the previous generations. One of the main goals of 4G will be the support of high data rate and multimedia services. Furthermore, The International Telecommunications Union (ITU) is specifying the requirements for the next generation mobile communication systems, the so-called IMT-advanced (IMT-A). IMT-A systems are expected to provide peak-data-rates in the order of 1Gbit/s in Local Area (LA) and 100 Mbit/s in wide area (WA).

In order to achieve a transmission velocity of 1 Gbit /second in the range of 100 MHz, which translates to 10 bps/Hz, a higher modulation is needed since the highest mobile phone modulation (64QAM) achieve up to 6 bps/Hz. Hence other techniques for reusing the same spectrum are needed, for instance, using of space dimension (i.e. antennas).

The standardization of UTRAN (UMTS Terrestrial Radio Access Network) LTE (Long Term Evolution) has started in the first half of 2005 and it will practically set the main reference for next generation systems assumptions[1].

As a final conclusion on the developments taking place in 2006, many of the proposed 4G solutions were based on Orthogonal Frequency Division Multiple (OFDM) modulation. Claims were being made that OFDM was the modulation of choice for 4G in the way that CDMA had become for 3G [1].

Orthogonal Frequency Division Multiple Access (OFDMA) should be suitable for downlink whereas Single Carrier Frequency Division Multiple (SC-FDMA) access should be proper for uplink, as will be explained in Section 2.3.2.

Concerning modulation and access method for next generation wireless networks, OFDM is considered as a good choice due to its good spectrum efficiency (better usage of spectrum) and tolerance to inter-symbol interference (ISI). Indeed, interestingly, the Japanese plans for a 4G technology talk of an OFDM-based solution in the 36 GHz band providing up to 100 Mbits/s of data [1]. The favourable use of SC-FDMA for uplink corresponds to the fact that this scheme provides a suitable way to spread energy and reduce the peak to average power ratio (PAPR). It represents an improvement in the user device in terms of power level needed for the transmission[32].

One of the objectives of this project is interference modelling. It can be studied focusing in different items. One of them can be depending on the different access techniques used; OFDMA and SC-FDMA, both based on FDMA, which can assign a band of frequency (channel) to only one user at a time [20].

For the particular case of study, the scenario of this research will be Time Division Duplex (TDD). The main reason for choosing it instead Frequency Division Duplex (FDD) is that it can dynamically adjust to varying traffic patterns and it is good for asymmetric communications where downlink and uplink traffic is not the same [22].

Network synchronization in TDD-based systems is more complicated than in FDD-based systems. However, this issue can be easily treated in LA scenarios because the range of the cells will be quite small. Since reducing interference is a very significant goal to improve the quality of communications, studying and modulating these interferences in LA-TDD scenario will be the main task for this project. In particular, three cases of synchronization will be studied and their performance for different techniques will be evaluated, in order to get a clear idea of their benefits / drawbacks.

1.2 General Scenario

To introduce the target scenario the main concepts about network issues will be introduced for, afterwards, go deeply in project delimitations. The target scenario consists of a wireless LAN for a small indoor office (also called Picocell) so these two terms will be briefly introduced in this section.

As was previously said a local area network will be considered, also known as LAN. LAN is a network covering a small geographic area such a home, office, building or campus. The characteristics of LAN permits achieve 1 or 2 Km and higher data rates than in the networks with more coverage area. Nowadays, the most common technologies for this kind of networks are Ethernet, over twisted pair cabling, and wireless technology [9]. Our scenario will be a cellular wireless LAN which is a small area scenario focused on cellular mobile communication. In mobile communications, cells can have different sizes; the one considered in this project is the smallest one, also called picocell.

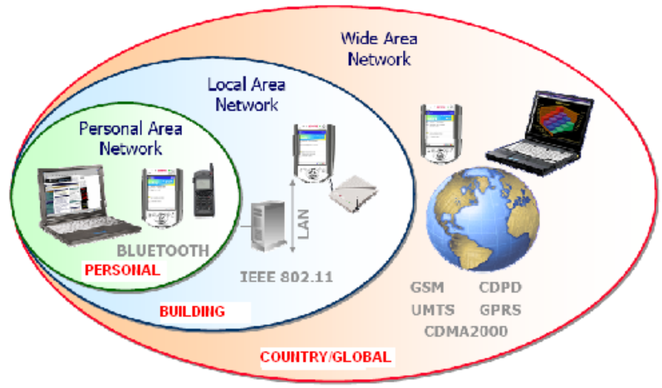

Figure 1.2: Different area networks[10]

Picocells consist of low-cost base stations in indoor cellular networks. Many objects, such as walls, may obstruct the communication in this case of environment hence the level of interference and attenuation of the transmitted signal will be significant. Picocells coverage used to be around 100 meters [16] . Picocells cellular networks are usually utilized to extend coverage to indoor areas where the outdoor signals do not reach well. Furthermore, picocells are also used to add capacity in a network with a lot of traffic, where a very dense phone usage is present, like in the airports or train stations[17].A significant performance gains in many different types of indoor WLAN deployments can be provided whenever picocells are well implemented .

1.2.1 Delimitation

For this project, three main scenarios with different coverage will be studied, each one composed of two LA indoor cells. A picocell mobile radio system will be considered, that is a local area architecture consisting of some wireless devices (MS's) connected to BSs, which are connected to the main network providing wireless connectivity to the covered area.

The spectrum used is performed as TDD spectrum division due to multiple advantages, which is introduced in Section 2.3.1, where the comparison against FDD is made.

In terms of synchronization and considering the flexibility of the spectrum usage, TDD is more complicated than FDD systems but, focusing on small indoor scenario, problems can be easier treated. The main objective for this project is the study and model of interferences and try to reduce them using spectrum allocation techniques.

As a starting point, a study of the target scenario is done for three different types of interferences: First of all, full synchronization case; which corresponds to the configuration of UL and DL belonging to the adjacent cells in a status of completely alignment (Further details explained in following chapters). Then, there is the loose synchronization case; which is the case when adjacent BSs have a difference in the time reference. Finally, the unsynchronization case; it occurs when BSs time references are completely different, UL and DL are not coordinated anymore.

The representation of different LA scenarios with its BSs and MSs will be analyzed and also the calculation of SINR depending on the synchronization case. So, after a study of the SINR for different scenarios, a comparison between them is done, then, one of them is selected to work with. Finally, some techniques are implemented in order to reduce the interference and improve the users SINR, trying to reach a better system performance.

Concerning spectrum allocation techniques, firstly, Sorting Approach algorithm (SA) is implemented. This technique consists of users allocation in the most favourable part of interference spectrum according with certain parameters that will be exposed in following sections. It is performed together with a proper Power Control (PC) technique whose aim is, a priori, to improve the results in terms of SINR. The performance for two different access schemes, OFDMA and SC-FDMA, are evaluated and compared with each other, in order to find the most efficient one out for the previous chosen scenario.

1.3 Thesis Structure

The document is structured in five chapters. In Chapter 1, an introduction and an overview of the scenario have been exposed. In Chapter 2, basic concepts and pre-theory part are explained in order to make the report easier to understand. In Chapter 3 , a theoretical part is presented but more focused on the aims of the project and on the implementations for the simulator. In Chapter 4, all results with newly implemented techniques are shown , as well as the explanation of the results. Finally, in Chapter 5, research conclusions are exposed and also the future work that can be researched in order to improve the results achieved.

Chapter 2

Basic concepts

2.1 Spectrum

The radio frequency spectrum is a small part of the electromagnetic spectrum, covering the range from 3 Hz to 300 GHz. A certain type of electromagnetic waves, called the radio waves, are generated by transmitters and received by antennas. The radio spectrum is the home of communication technologies, such as mobile phone, due to its excellent ability to carry codied information (signals). Depending on the frequency range, the radio spectrum is divided into frequency bands and sub-bands assigned for different usages.

It is crucial to have a harmonized spectrum for all regions and countries to have a suitable worldwide development for the mobile systems. In November 2007, ITU defined the ones used by the International Mobile Telecommunications [14]:

- 450-470 MHz band frequencies to be used by IMT technologies.
- 698-862 MHz band in Region 2 and nine countries of Region 3.
- 790-862 MHz band in Regions 1 and 3.
- 2.3-2.4 GHz band frequencies to be used by IMT technologies.
- 3.4-3.6 GHz band (C Band): it is no global allocation, but accepted by many countries.

Regions and its respective countries are listed in [15].

2.2 Wireless channel

Wireless channel is very unpredictable with challenging propagation situations.

In an ideal wireless channel, the received signal is a reconstruction of the transmitted signal. However, in real radio systems, the signal would be modified during its transmission along the channel. For more details see the Appendix A.

Wireless channel is characterized by:

- Path loss
- Fading
  - Fast fading
  - Slow fading (shadowing)

2.2.1 Path loss

Path loss is the attenuation of the signal while it is propagated through space. Waves sometimes can not travel over the horizon because they run into obstructions, for this case, path between transmitter and receiver will be a no direct line of sight (NLOS). If no obstructions are present , it will be a direct line of sight (LOS) path. Furthermore, propagation path can be LOS even if the transmitter is too distant to be seen by human eye. LOS and NLOS can be seen in Figure 2.1.

Figure 2.1: LOS and NLOS

Due to the propagation characteristics, electromagnetic waves suffer a reduction of the power density. Path loss is a very relevant task when analyzing the links between the receiver and the transmitter in telecommunication systems.

Path loss can be caused by many effects [6]:

- Free-space loss
- Refraction: change in direction of a wave due to a change in its speed, usually when It passes form one medium to another.
- Diffraction: natural tendency of the wave to bend around the obstacle resulting in a change of direction of part of the wave energy.
- Reflection: waves bounce from a surface of the object back toward the source.
- Coupling loss: occurs when wave is transferred from one medium to another.
- Penetration loss: occurs when the wall or the obstacle absorbs part of the signal.

The path-loss model is defined in Equation 2.1 , where d is the distance between transmitter and receiver, A is the parameter that includes the path loss exponent and B is the intercept parameter. The specific equation used for our simulations is explained in Section 4.1.

$$PL = A \cdot log(d) + B \tag{2.1}$$

2.2.2 Fading

Fading occurs when there are significant variations in both received signal amplitude and phase over time or space. These variations are usually because of the effects listed on 2.2.1.

In order to measure the fading there are two criteria: doppler spread and delay spread[7].

Doppler effect is caused by the relative movement of the transmitter and the receiver. It can be described as the effect produced by a moving source of waves in which there is an apparent shift in frequency for observers from whom the source is receiving. A coherence time is defined to quantify the time-variation of the channel [7].

Delay spread (Ds) is the time interval between the arrival of the main wave, which has line of sight (LOS), and the arrival of the last multipath signal, which do not have line of sight (NLOS). It provokes temporal dispersion of the signal. The spread of the signal in time domain may cause ISI (Inter Symbol Interference) at the receiver if the period of baseband is larger than the one of delay spread. ISI is when receiver can not distinguish between data signals of two adjacent pulse periods because they are both received at the same time. The coherence bandwidth establishes the maximum bandwidth that can be transmitted through a specific channel to avoid ISI.

Fading can be temporal or spatial interpreted. In time domain, coherence time is the parameter that measures the minimum time required for the magnitude change of the channel to become decorrelated from its previous value, it is the period of time in which the channel does not change a lot. The coherence band (Bc) is the inverse of the coherence time so it is also the band in which the channel keeps its characteristics constant. The equation to calculate the Bc is the following [7]:

$$Bc = \frac{1}{2 \cdot \pi \cdot Ds} \tag{2.2}$$

In spatial domain it relays in the separation between the mobil antennas (ε) to have effective spatial diversity. Correlation must be bigger than 0.5 as can be seen in [7]:

$$\tau = \frac{\varepsilon}{\lambda} > 0.5 \tag{2.3}$$

Slow fading vs Fast fading There are two kinds of fading, slow fading and fast fading. Both slow and fast fading are related to the rate at which the magnitude and phase change imposed by the channel on the signal changes. As can be seen in the following figure, for fast fading the signal changes a lot with the distance, while the slow fading is more constant [1].

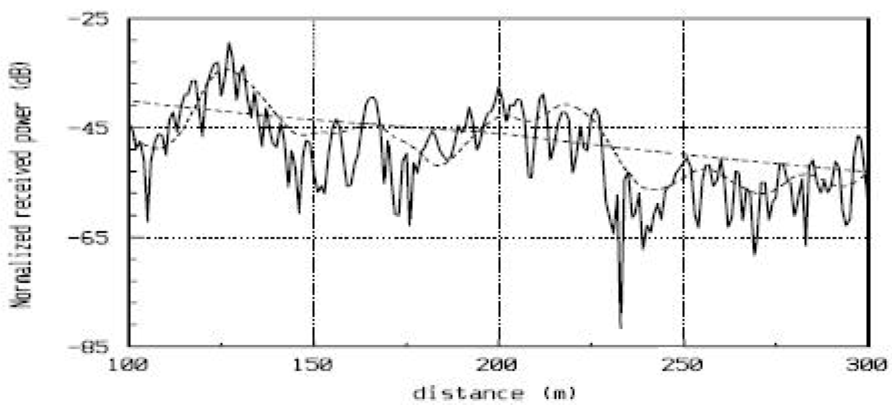

Figure 2.2: Fast and slow fading [10].

Since fast fading is not relevant for our scenario, further explanations will be focused on slow fading.

Slow fading is caused by shadowing can modify the coverage zone. It occurs whether an obstacle is placed between the MS and the BS that obscure the main signal path, so, the received signal power fluctuates.

In this fading, both amplitude and phase can be considered constant during a period of time because it changes very slowly. Focusing on time domain, coherence time (time interval with the smallest amount of fading) is longer than the delay of the channel. Slow fading can not be corrected by time diversity because the transmitter can just see a part of the channel with the delay constraint.

The slow variation of the power is usually modelated as a lognormal probability density function (PDF). PDF is an statistical measure that defines a probability distribution for a random variable. In this case it means that the local-mean power expressed in logarithmic values has a normal or Gaussian distribution.

2.3 Multiple access principles

For being able to understand clearly our research a brief explanation about all the parameters involved in our project definition will be explained in the following Section.

2.3.1 FDD and TDD

In FDD (frequency duplex division) downlink and uplink operate in different bands of frequency and there is a band guard between them to make the filtration easier and minimize the interferences.

FDD means that each channel has a fixed band and a fixed capacity as well. The paired channel separation use to be 100 MHz (see [TTG]) as is shown in Figure2.3. It is good for symmetric communications as voice.

One of the advantages of FDD is that the uplink and downlink transmission are continuous and simultaneous. Hence it is more robust because the UL and DL bands are spaced and the burst operations are simplified[22]. Another advantage is that the interferences between Base Stations (BS) and between Mobile Stations (MS) are minimized and smaller because of the large band guard between UL and DL. Finally, frequency planning is easier for FDD than in TDD systems[21].

These systems have also some disadvantages and it is important to take them into account. The main disadvantage is that the UL and DL channel allocations are fixed, so, when traffic is asymmetric, a lot of bandwidth is wasted . Furthermore, a frequency band guard between UL and DL is also needed. Finally, FDD is more expensive since UL and DL operate in different frequency bands and more hardware resources are needed. Separate filters, separate oscillators and a diplexer are needed to avoid very high interferences. As was said before, FDD can not adapt to dynamic UL and DL traffic.

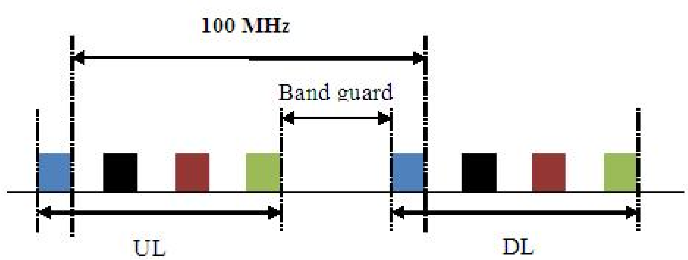

Figure 2.3: Frequency duplex division[10]

In TDD (time duplex division) downlink and uplink operate in the same frequency band but in different time slots. Hence a frequency band guard is not necessary anymore and neither a paired channels for uplink and downlink communications. However, as is shown in Figure 2.4 there is a guard interval between DL and UL and between UL and DL in order to avoid overlaping. The first one is called TTG (Transmit/receive Transition Gap) and the second one is called RTG (Receive/transmit Transition

Gap). TTG use to be larger than RTG to give enough time to the further signals of the sector for the round-trip delay [21].

One advantage of TDD is that its characteristics permits to assign resources asymmetrically, so the utilization of the spectrum is more efficient like only a little time width is wasted because of the guard periods. Furthermore, it can be not considered because is very small compared to the total length of data in a time slot [23].TDD system is a good choice if the traffic is unpredictable or asymmetrical because it is possible to allocate the bandwidth flexibility by altering the duration of the sub frame. This is a very important advantage of these systems because the asymmetrical traffic is expected to increase in the future. Another advantage of TDD is that uplink and downlink use the same channel, so the channel responses between forward and reverse may be assumed to be reciprocal of one another. With a reciprocal channel, the channel response for one link may be estimated based on a pilot received via the other link and the station will be able to optimize the transmit parameters [24]. Finally, the hardware costs of TDD systems are lower because UL and DL share the oscillators and the filters and a duplexer is not needed anymore

Refering to TDD, the main disadvantages are because of the interferences arises when neighbouring base stations do not synchronise their frames and have different UL and DL symmetries[21]. There are also the interferences between operators using adjacent channels that can be higher because their cells can be overlaped and it can provoke adjacent channel interference (ACI). Each operator and BS's in the area have their own distribution of the cells but if they cooperate and put the BSs using adjacent channels physically separated interference could be minimized[25]. Finally, as we explained before, TTG and RTG guard intervals are needed and TTG interval must be larger than the round-trip delay, so, if the cells are big, also the TTG will be big and the efficiency of the system it can be reduced. As was said before, our focus scenario is a LAN so it will not affect our system.

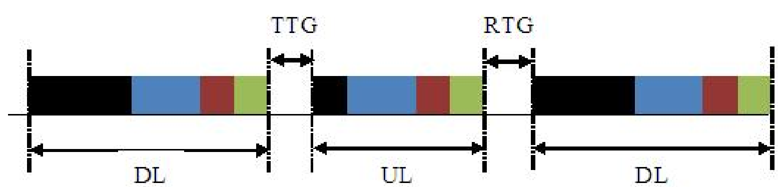

Figure 2.4: Time duplex division [10][21].

2.3.2 OFDMA and SC-FDMA

OFMDA is also called Orthogonal FDMA. Orthogonal means that the peak of one sub-carrier coincides with the null of an adjacent sub-carrier. In OFDMA there is a tight space between subcarriers and can come up with an inevitable offset in the uplink frequency references among the different subscriber stations (MSs) that transmit simultaneously. Inter carrier interference (ICI) occurs between two neighbouring subcarriers that belong to different MSs [27]. The orthogonality will be destroyed and introduces multiple access interference.

This access technique is robust in presence of multipath signal propagation in the radio channel because of the big size of the OFDMA symbol times (order of 100 microseconds) [28]. Without multipath protection, the symbols in the received signal can overlap in time and cause ISI which can be avoid adding a cyclic prefix (CP). CP is a part of the signal which is added between symbols as a band guard. If multipath delay is shorter than the cyclic prefix, neither intersymbol or intercarrier interference will be present. On the other hand, some loss in eficiency is introduced as carried prefix does not add new information.

SC-FDMA is a single carrier multiple access technique which has similar structure and performance to OFDMA but there is one step more. It does not transmit the data symbols in parallel (one per subcarrier) like OFDMA (Figure2.6), regardless the complexity is essentially the same. In SC-FDMA the data symbols are transmitted sequentially in a bigger data rate and each one is occupying the whole bandwidth within the symbol period. Hence, SC-FDMA combines the low peak-to-average ratio (PAPR) of traditional single-carrier formats with the multipath resistance and the in-channel frequency scheduling flexibility of OFDM.[32]. The block diagrams of OFDMA and SC-FDMA schemes can be seen in Figure 2.5.

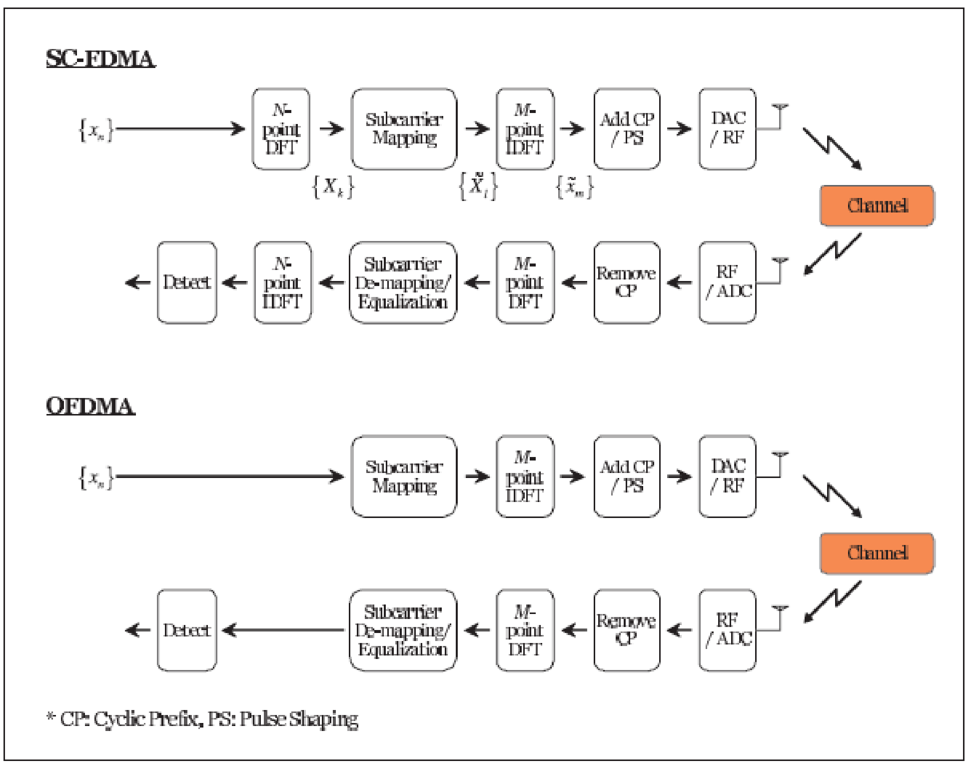

Figure 2.5: OFDMA and SC-FDMA [35]

Since each data symbol is spread in the band, this technique should be more robust to the spectral nulls because as long as a null in OFDM symbol will affect the whole symbol, with SC-FDMA, it will be more difficult to loose the whole data symbol.

As was explained before, SC-FDMA contains sub-symbols (data symbols) of much shorter duration. The resistance of the multipath in OFDMA seems to relay on long data symbols that are mapped into M subcarriers operating at a 1/M times the bit rate of the information signal. Anyway, in OFDMA, the resistance to delay spread does not depend on data symbols duration. This shows why SC-FDMA with short symbols duration is also resistant to multipath [32].

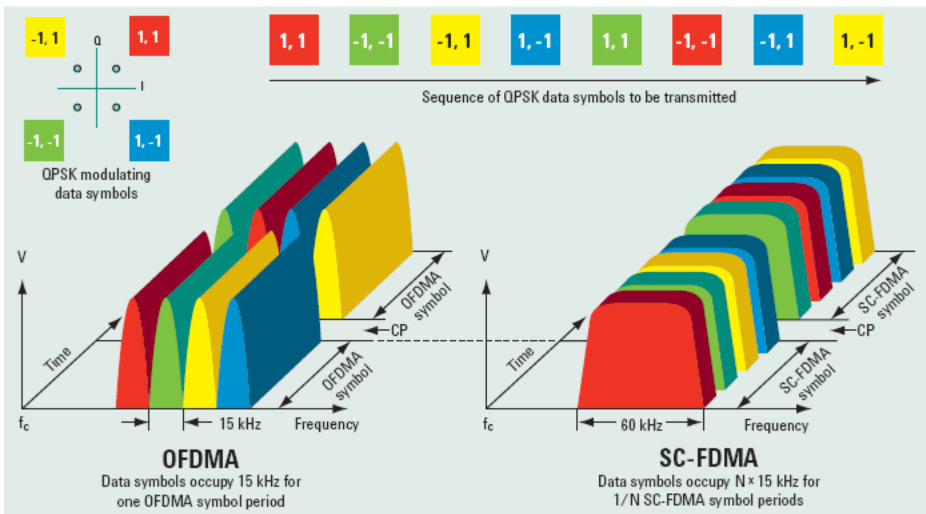

Figure 2.6: OFDMA and SC-FDMA data symbols transmision[32].

Localized and Distributed Modes In localized mode (LFDMA) the DFT outputs (symbols) of each terminal are allocated occupying adjacent subcarriers resulting in a continuous spectrum.

In Distributed mode the DFT outputs of each terminal are allocated over the entire bandwidth in a non continuous shaped spectrum, the subcarriers used by one user are spread in the band. This makes this mode robust against the frequency selective fading because the information is spread across the signal band and it offers frequency diversity. So if the channel has a null in one part of the spectrum the information of one concrete user wont be completely lost [33] .

PAPR PAPR is defined as the ratio of peak to average power of the transmitted signal in a given transmission block [35]. So, with multicarrier modulations the PAPR is higher and it is not good for our systems. High PAPR means that the peak values of some transmitted signals would be larger than the typical values and linear circuits with large dynamic range will be needed. On the other hand, with high PAPR would provoke a distortion of the transmitted signal out-of-band radiation.

A solution is to use single carrier modulations because as it has explained before the subcarriers are spread and are transmitted sequentially, the PAPR will be lower.

Anyway, configurations with lower PAPR tend to have lower throughput as can be seen in [34] and this item is also very important for our systems. Throughput varies depending on the way in which information symbols are allocated to the subcarriers, it means that the use of LFDMA or IFDMA can have influence on its performance.

Summary One advantage of OFDMA is that the manipulation of signal phase and amplitude is easier to implement than in single carrier systems, which represents the signals in time domain [32]. The problem of OFDMA is that when the number of subcarriers increases, the time domain signal starts to look like Gaussian noise and the waveform exhibits very pronounced envelope fluctuations hence high PAPR. The problem can be solve by transmitting the subcarriers sequentially, like SC-FDMA. The envelope fluctuations will be reduced and increasing the number of data symbols the PAPR remains constant (the same than original data symbols) because it is all transmitted in just one subcarrier.

SC-FDMA has also less sensitivity to both carrier frequency offset and non-linear distortion in the amplifier. However, it has some inconvenient as well, which is the relation between channel bandwidth and symbol length. Single carrier systems do not scale well when the channel bandwidth becomes wider and they are not practical when the delay differences are long [32]. SC-FDMA needs more time domain processing and it would be a problem on the base station that has to manage the transmission for multiple users, for this reason it works better in UL communications with high data rate[32].

Some conclusions can be achieved referring to localized and distributed modes in single carrier FDMA. First of all, in terms of PAPR we have seen that SC-FDMA outperforms OFDMA. However, it is important to know that the difference is bigger when differing between SC-LFDMA and SC- IFDMA, since the second one has lower PAPR than the first one.

LFDMA is also better working with a few users with high data rate while IFDMA is better in systems with many users transmitting at moderate bit rate [32]. As was said before, other important characteristic of IFDMA is its lower outage probability (because the signal is spread) and it works well with static subcarrier scheduling. Static subcarrier scheduling assigns subcarriers to users without take in account the channel conditions [34].

Chapter 3

Interference Modelling

3.1 Interferences

3.1.1 MSs and BSs interference

Interferences among adjacent cells can take place between either a MS and a BS, two BSs or two MSs.

MS to BS interference This interference is present in all systems, although it is more clear when the network is fully synchronized and when both cells have the same UL to DL ratio. It takes place when the MS is transmitting and the adjacent BS is receiving at the same or adjacent frequencies, so the MS interferes to the other BS of the scenario[37]. Since the signal quality decreases with the distance, MS to BS interferences will be specially problematic when MS's of adjacent cell are close to the border between the two cells.

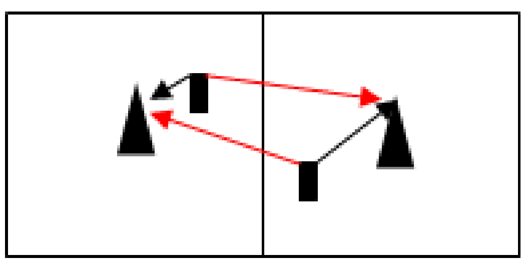

Figure 3.1: Interference from MS to BS

BS to MS interference This interference is also present in all systems but it is more clear when the network is fully synchronized and when both cells have the same UL to DL ratio. It takes place when the BS is transmitting and the MS of the adjacent cell receiving at the same or adjacent frequencies, so they both interfere one to each other. Again, since the signal quality decreases with the distance, BS to MS interferences will be specially problematic when MS's of adjacent cell are close to the border between the two cells.

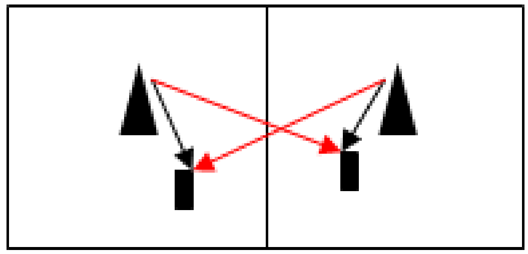

Figure 3.2: Interference from BS to MS

BS to BS interference This interference is present in the systems that are not fully synchronized. It occurs when one BS is transmitting and the BS of the adjacent cell is receiving at the same or adjacent frequency. In other words, when they have different UL to DL swiching point. The path loss between the two base stations is very important in this kind of interference.

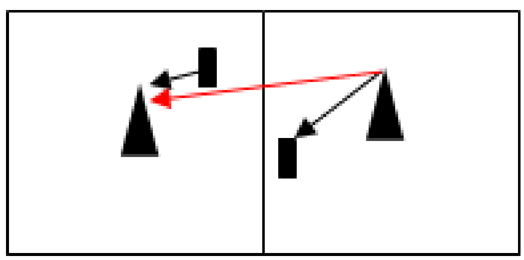

Figure 3.3: Interference from BS to BS

MS to MS interference This interference is present in the systems that are not fully synchronized too. It occurs when one MS is transmitting and one MS of one of the adjacent cells is receiving in the same or adjacent frequency, so when they have different UL to DL swiching point. The mobile to mobile interference is difficult to define because the position of the MS is changing all time long and cannot be controlled. This interferences will be higher when both MS's from different cells are transmitting and receiving at same frequencies are close to the border.

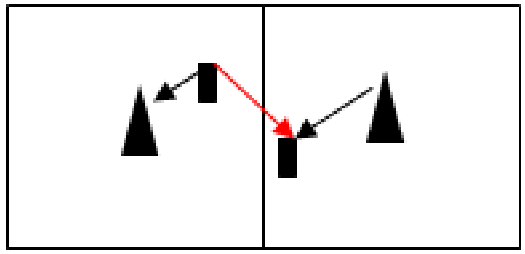

Figure 3.4: Interference from MS to MS

3.1.2 Synchronization Interferences

The synchronization interferences are the ones produced between two cells because one is in UL transmission and the adjacent one in DL transmission. These interferences appear in TDD when adjacent BS's are not synchronized because the two transmission directions share the same frequency. As is seen in Section 3.1.1, UL-DL interference can occur either between two BS or two MS but if the synchronization is perfect there will be interferences between MSs and BSs.

In order to study the synchronization, three different cases will be presented: Full synchronization, Lose synchronization and Unsynchronization

Full synchronization In this case the UL and DL of the two adjacent cells start in the same time reference during the communication, the two BSs will have the same time reference.

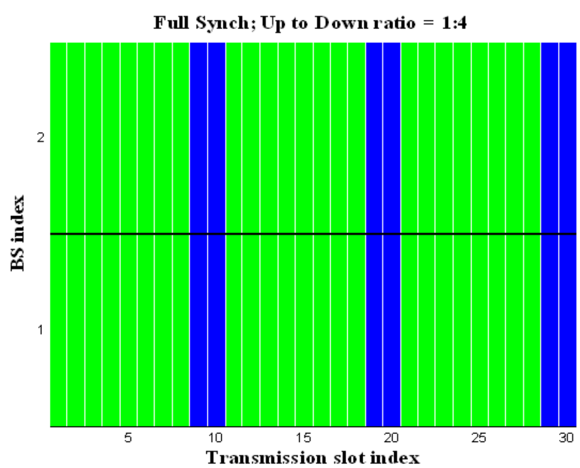

Figure 3.5: Two full synchronized cells

Loose synchronization This case takes place whenever the synchronization is not perfect, so there is a small difference between the time references of the BSs. This difference can be one slot or more but in our simulations just one slot mis-match is considered.

Figure 3.6: Two cells loosing synchronization

Unsynchronization It is when there is not synchronization between the two cells hence the time of reference is completely lost. It uses to happen when the BSs belong to different operators and they do not cooperate.

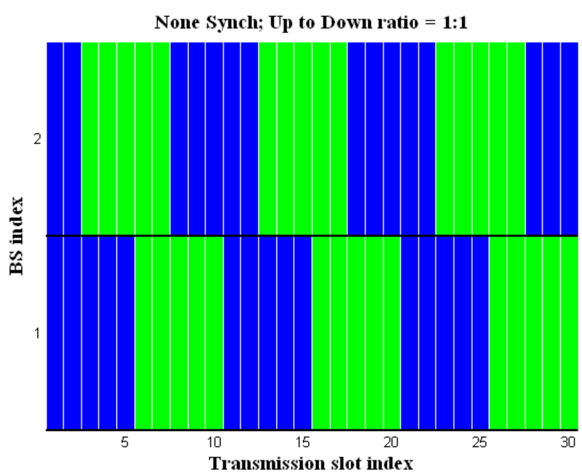

Figure 3.7: Two unsynchronized cells

3.2 Sorting approach and power control

3.2.1 Sorting approach

Concerning the bandwidth setted for this study, the same gain for all frequencies along the spectrum is considered. This fact leads us to not consider different channel response affecting each user. The previous assumption is correct in terms of frequency spectrum but, if more than one cell are considered in the scenario, an interference spectrum has to be taken into account. This interference spectrum appears due to the links established between either of the elements in the adjacent cell, and the effects in the interference appear, depending on the physical situation of the elements and the transmitted power used by each one.

TDD scenario is considered for this study, so, a division of time in order to alternate between UL and DL transmission links is performed. In this sense, a division of the bandwidth is not done, and the BS transmits and receives using the whole spectrum .

Due to previous assumption, different cells use same portion of spectrum at the same time, hence the transmission between the BS and one UE in cell 1 can interfere in the reception of the BS and a UE belonging to cell 2. Together with this, it has to be considered that, due to the random allocation, users from different cells can be set very close one to each other in the cells border. In that case, the power coming from different BS could be comparable giving us high levels of interference as is shown in Figure 3.8,

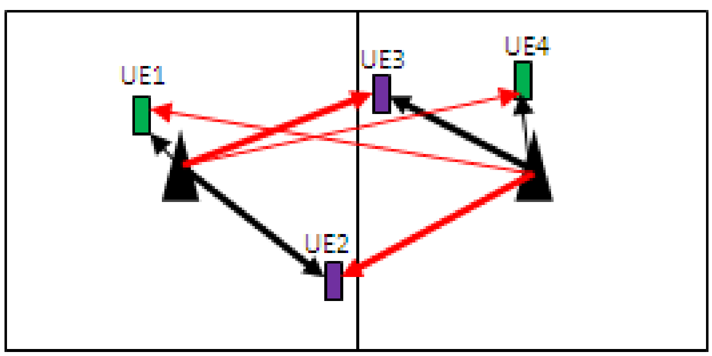

Figure 3.8: Very high interference for UE2 and UE3 and very low for UE1 and UE4

The goal of Sorting Approach (SA) is to allocate the carriers belonging to each UEs properly in different parts of the interference spectrum. This algorithm is performed in order to avoid the use of a very close geometrical position and identical spectrum bandwidth at the same time by users from different cells. Fig.3.9,

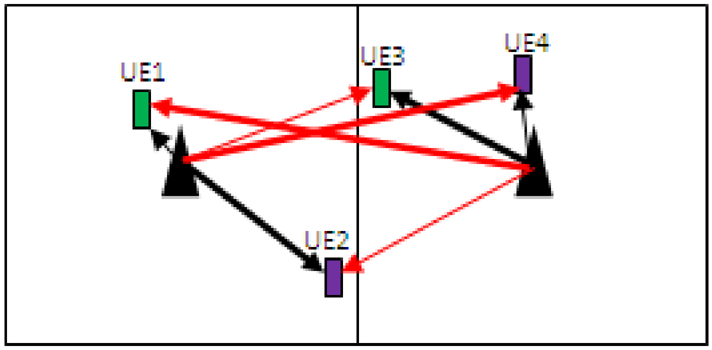

Figure 3.9: Mid interference for all users

The allocation of the carriers group for each UE is performed according to an specific parameter. It is the ratio of path loss communication link for that user over the sum of the path loss of interference links that reach the user (called UEs path loss ratio level for Figure 3.10). In the first cell, the carriers of users are allocated following an order from the UE with higher ratio to the UE with lower one. This allocation is performed in the opposite way for adjacent cells as we can see in Figure 3.10,

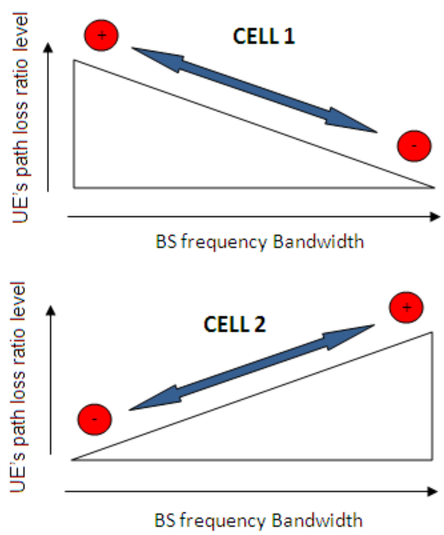

Figure 3.10: Path loss difference

Hence, the transmission that a UE is having with its BS is producing less interference level to the UE belonging to the adjacent cell. Calculating the previously mentioned ratio, a quality of link can be set for each UE and a better SINR can be reach.

3.2.2 Power Control

In order to improve the final results for SINR, a suitable Power Control (PC) configuration is considered in the simulations. It is based on the adaptation of the power transmitted depending on the link path loss together with the SNR wanted to reach. The mechanism provides more power to links which have high losses in the path, and less power links which have more gain. All the power transmitted is checked in order to fit in the thresholds set for this study. In this case the Equation used to calculate the transmitted power is,

$$Ptx = \frac{Pn \cdot 10^{\frac{targetSNR}{10}}}{\alpha \cdot pathgain} \tag{3.1}$$

where Pn is the channel power of noise, target SNR is the signal to noise ratio wanted to reach and path gain is the gain of the channel calculated using link path loss and $\alpha = 1$.

3.3 Effective SIR Mapping (ESM)

First of all, some parameters utilized for determinate the quality of the signal will be briefly explained. Afterwards, EESM method will be introduced with the corresponding calibration of the parameter β.

3.3.1 Parameters definition

Signal to Noise Ratio (SNR) SNR is a parameter used to check the quality of the transmission. Noise damages the interested transmission, it is random and unavoidable and comes from natural sources. SNR is given by the relationship:

$$SNR = \frac{S}{N} \tag{3.2}$$

, where S is the transmited power and N is the noise.

Signal Interference plus Noise Ratio (SINR) is a parameter used to check the quality of its transmission from the transmitter to the receiver. It is the same than before but in this case the interferences from other communications are also taken into account. This parameter is given by the relationship:

$$SINR = \frac{S}{I + N} \tag{3.3}$$

,where S is the transmitted power, I is the interference caused by other transmissions and N is the noise.

Block Error Rate (BLER) is a ratio of the number of erroneous blocks to the total number of blocks received on a digital circuit. It is used to determine the quality of the radio link. Its value ranges between 0 and 100%. The lower the value of BLER, the better the quality of the radio link. The equation to measure this parameter is the following:

$$BLER = \frac{Nerror}{Nwindow} \tag{3.4}$$

,where Nerror is the number of erroneous blocks received over a period corresponding to the blocks transmitted in the window size (Nwindow).

3.3.2 Introduction and Link adaptation

Link adaptation involves choosing the Modulation and Coding Scheme (MCS) suitable for the channel conditions in order to achieve optimal system performance.

It is well known that link adaptation can lead to a significant performance gains to wireless systems as shown in [47].

Channel variation, in both time and frequency domain, need to be considered when the system is multicarrier. In case of time dimension, link adaptation method can be classified as fast or slow depending on the Doppler conditions . For frequency domain, the link adaptation can be either frequency selective(FS) or frequency diverse(FD) [48]. The FS choose the suitable MCS among a group of subcarriers based on the quality of the subcarriers whereas the FD choose the MCS for a whole set of subcarriers of a frame based on some form of average quality indicator, such as the band averaged SNR.

The most straightforward average channel quality indicator choses the MCS using the average SNR over the subcarriers of the previous frame [48]. However, it has been shown in [49] that this method with OFDM shows a low performance due to the SNR alone does not properly describe the channel quality.

Since an inappropiate estimation of MCS can reduce the throughtput (always that the MCS is too low) or additional retransmissions(whenever that MCS chosen is too high), another tecnique has been found to provide accurate results for link error prediction, that is the Exponential Effective SNR Mapping method.(EESM)

Traditionally, EESM has been used for link error prediction but due to the high accuracy of the method together with the fact that it does not require knowledge of the channel delay spread or power-delay profile, so EESM-based MCS selection is attractive for OFDM systems [48].

Also, EESM was introduced as a valuable method to abstract the coding part of the simulation and, hence save great amounts of time [42][43].

Recent publications have shown that EESM is a very useful method to predict the frame error rate (FER) for multicarrier modulation systems in frequency selective channel [44][45].

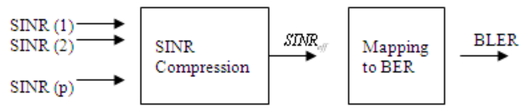

Figure 3.11: Mapping from SINRs to SINRs eff

3.3.3 Derivation of the EESM

The mapping is derived from the Chernoff union bound for bit error rates for uncoded Binary Phase-shift keying (BPSK) transmissions but EESM can be extended to different codes and higher modulations by adjusting the parameter β .[41].

For Binary Phase-Shift Keying (BPSK) transmission over an Additive White Gaussian Noise (AWGN) channel, assuming Signal to Noise Ratio (SNR) and a symbol distance of 1, the probability of error Pe is: [41].

$$Pe(\gamma, 1) = Q(\sqrt{2\gamma}), \tag{3.5}$$

Assuming a high enough SNR(SNR $>$ 6dB), equation 3.5 can be upper bounded using the Chernoff union bound (expained in [57])

$$Pe(\gamma) \leq e^{-\gamma} \tag{3.6}$$

For transmissions over N_{AWGN} channels with SNRs γ_i the probability of at least one error becomes:

$$Pe = 1 - \prod_{i-1}^{N}(1 - Pe(\gamma_i)) \approx \sum_{i-1}^{N} e^{-\gamma_i} \tag{3.7}$$

That is the block error rate for N symbols.

For finding the equivalent SINR γ_{eff}value with the same Pe, setting $\gamma_i = \gamma_{eff}$

$$Ne^{\gamma_{eff}} = \sum_{i=1}^{N} e^{-\gamma_i} \tag{3.8}$$

Solving we get:

$$\gamma_{eff} = -ln\frac{1}{N}\sum_{i=1}^{N} e^{-\gamma_i} \tag{3.9}$$

For QPSK:

$$\gamma_{eff}, QPSK = -2ln\frac{1}{N}\sum_{i=1}^{N} e^{-\frac{\gamma_i}{2}} \quad (3.10)$$

The assumption made can be use this mapping for higher modulations and also for coded transmissions by adjusting the parameter β:

$$\gamma_{eff} = EESM(\gamma, \beta) = -\beta \ln \frac{1}{N}\sum_{i=1}^{N} e^{\frac{\gamma_i}{\beta}} \quad (3.11)$$

Where $\gamma_i$is the tone SINRs and β is the parameter to be determined for each Modulation Coding Scheme(MCS) level.

3.3.4 Calibration of β

In order to calibrateβ several realizations were studied from different channel models.

All simulations for calibration have been taken from [51] and the simulation conditions are described below.

The frequency response of each channel instantiation remained constant over the length of the corresponding simulation, although the specific AWGN noise applied to the transmitted signal varied between different TTIs. (The power of the AWGN noise was constant.)

Each simulation lasted for 10000 TTIs or until 200 TTI block errors had been observed, whichever came first. Simulation points with observed block error rates between 1% and 80% inclusive were used to estimate appropriate β values for each link mode.

Equation 3.11was then used to estimate the corresponding effective SIR for different candidate values of β . The appropriate value of β for each link mode was selected as the value that minimized the effective SIR estimation error term defined as:

$$Error_{eff} = \frac{1}{N_{BLER}}\sum_{m}[(SIR_{eff})_m - (SIR_{AWGN})_m]^2 \quad (3.12)$$

where N_{BLER} is the number of useful simulated BLER points (i.e. in the range from 1% to 80%) for the link mode being considered, $(SIR_{eff})_m$ is the effective SIR value for the mth BLER point as calculated from Equation 3.11, and $(SIR_{AWGN})_m$is the SIR value from the AWGN BLER curve.

Table 3.1 contains suitable ß values for system-level performance evaluations estimated using the MMSE criterion defined in Equation 3.12.

Modulation	Code Rate	# of BLER Points	β
QPSK	1/3	191	1.49
	1/2	132	1.57
	2/3	159	1.69
	3/4	186	1.69
	4/5	111	1.65
16QAM	1/3	115	3.36
	1/2	198	4.56
	2/3	129	6.42
	3/4	123	7.33
	4/5	120	7.68

Table 3.1: Modulations and code rates

Chapter 4

Interference Simulation Results

4.1 Specific scenario & assumptions

A properly description of scenario modelling is needed in order to provide a suitable knowledge about the reach of this study. The choose target scenario layout is a single floor office divided in two cells composed by square rooms and one base station belonging to each cell.

In order to generalize this work, three different configuration of mentioned scenario has been considered. In the first case, 1x1 room per cell is set. In the second case, cells with dimensions of 5x4 rooms are studied, with one base station allocated in their centre and with cells separated by a corridor. Finally, 10x2 rooms per cell are set with two base station allocated in the middle of the corridor. The size for the square rooms has been set as 10 meters of side, and for corridor as 5 meters of wide.

Concerning physical and geometrical settings for the elements in the scenario, the users and base stations are represented as square figures with 1 meter of side for users, and 2 meters of side for base stations case. The height for users and for office's roof is also took into account. The allocation of UEs inside the cell is performed randomly.

Together with mentioned physical features, multiple variables for signal and transmission channel are considered to reach more realistic results in the evaluations.

For base stations and users, omnidirectional propagation for the signal is considered. Concerning transmission profile, an UL/ DL ratio parameter can be set, in order to manage the amount of bandwidth dedicated to each one. Minimum and maximum thresholds for transmitted power are set for users and base stations. Also temperature power of noise is defined in the calculation settings, using a figure of noise of 9dB, and calculated as,

$$Pn = k \cdot T \cdot B \cdot 10^{\frac{9}{10}} \tag{4.1}$$

where k represents Boltzman constant, T temperature in Kelvin degrees and B the bandwidth used for each group of subcarriers (PRB), which is calculated considering 12 carriers per PRB and 15KHz of bandwidth per carrier.

Shadow fading is considered in some of the evaluations. For following cases, a log-normal distribution with maximum deviation of 3 dB is taken into account.

In order to set the features for the scenario path loss, the Indoor Office A1LOS model from Winner II project [52] is adopted. Following this model configuration, there are two different kind of links. In one hand, for the case of Line of Sight (LOS) link, the calculation is performed using Equation 4.2. which is set in function of the distance covered by the communication link among elements (d),

$$PL = 18.7\log(d) + 46.8 + Cf \tag{4.2}$$

On the other hand, if the signal reach any obstacle, the calculation for Non Line of Sight (NLOS) case is applied using Equation 4.3 . In that case, the total path loss is function of (d) and also of number of pierced walls (nw) by the signal, considering an attenuation factor of 5dB for each wall,

$$PL = 20\log(d) + 46.4 + 5\Delta(nw) + Cf \tag{4.3}$$

For both previous cases, a correction factor (Cf) is also needed which varies depending on the frequency used (fc), as can be seen on Equation 4.4,

$$Cf = 20\log(\frac{fc[GHz]}{5}) \tag{4.4}$$

The frequency used for the evaluations is 3.5 GHz. As can be previously seen, it is in the C Band and mobile systems (also referred to as IMT systems) are allowed to use the frequencies of this band [53]. The bandwidth used is 100 Mhz.

Concerning the indicators considered to perform the evaluations, SINR and SIR are calculated. The figures show these ratios in dB on the x axis, and the empirical cumulative distribution function (CDF) on the y axis. The empirical CDF for this study is representing the proportion of SINR values less than or equal to values in dB set in x axis.

For the described scenario, different type of evaluations have been performed in order to achieve clear profile of the interference behaviour. In Section 4.2, a study of the previous configurations introduced is done in order to find out the most properly one. In Section 4.3 techniques of spectrum allocation are considered to improve signal transmission results. Finally, in Section 4.4, EESM mechanism is implemented in order to compare SIR behaviour with effective SIR due to the fact that it is a quite realistic method to predict the BLER in frequency selective channel.

Simulations setup

- Single floor scenario
- Size of room: square with 10 meters of side
- Size of UEs: square with 1 meter of side
- Size of eNBs: square with 2 meters of side

- Frequency used: 3.5 GHz
- Bandwidth used: 100 MHz
- Randomly users allocation
- Omnidirectional propagation for the signal coming from users and base stations
- No limitation distance between BS and MS
- Only one Base station per cell situated in its geometrical centre of the cell
- From 5 to 10 users allocated randomly in the cell
- BS power: maximum 24 dBm and minimum 10 dBm
- MS power: maximum 24 dBm and minimum -30 dBm
- Power of thermal noise : 9 dB of noise figure
- Noise Temperature: 300 K
- Boltzman constant (k):$1.38 \cdot 10^{-23}$
- Bandwidth of noise: $15000 \cdot 12$
- Shadow fading is considered in some simulations with a standard deviation of 3 dB
- Gap between UL and DL is not considered
- Ratio parameter considered for UL/DL: 1:4, 1:1 and 4:1
- Time of slot is 1ms
- Number of slots per frame is 10
- 1000 snapshots

4.2 Study of the three different scenarios

In order to evaluate the different scenarios three types of synchronization are studied, these are when the system is full synchronized, when the synchronization is lost, it means that it is not perfect synchronized, and when it is completely unsynchronized. For each one of these cases, three different up-down ratios are considered: up-down ratio=1:4, up-down-ratio= 1:1 and up-down ratio=4:1. It means that in the first case the DL number of times slots is four times bigger than the UL and in the third one the UL is four times bigger than DL. In the second case UL and DL use same number of time slots.

After a comparison between different ratios for each type of synchronization, a comparison between synchronizations for each ratio is given. All of these simulations are carried out with three different scenarios in order to decide which one will be used for the following study. The Scenario 1 is the smaller one and has squared cells. It is compared with the Scenario 2, wich is bigger and has more rooms, in order to determine how affects the size of the cells. Then, Scenario 3 is similar than Scenario 2 but with rectangular cells. This comparision is done in order to determine if the SINR is better for squared or rectangular cells. Due to the linearity of shadow fading parameter, its inclusion is not critical to determine the most proper scenario. So, for the evaluation of these three scenarios it is not considered.

4.2.1 Scenario 1: 1 room per cell

4.2.1.1 Simulation condition

In this first simulation our scenario is formed by two small rooms with one base station in each one and several terminals placed within both rooms, as is shown in the followind figure.

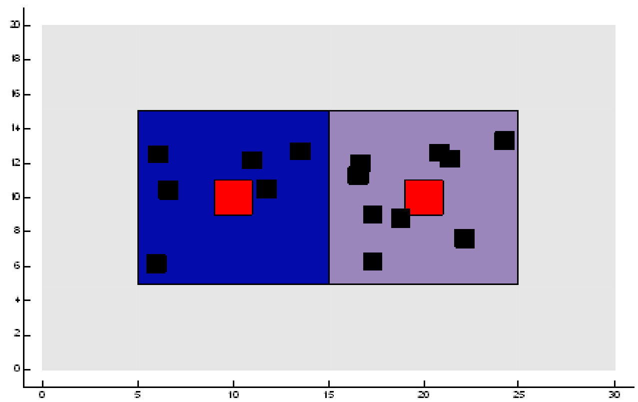

Figure 4.1: Scenario 1

4.2.1.2 Study of different ratios

Full synchronization

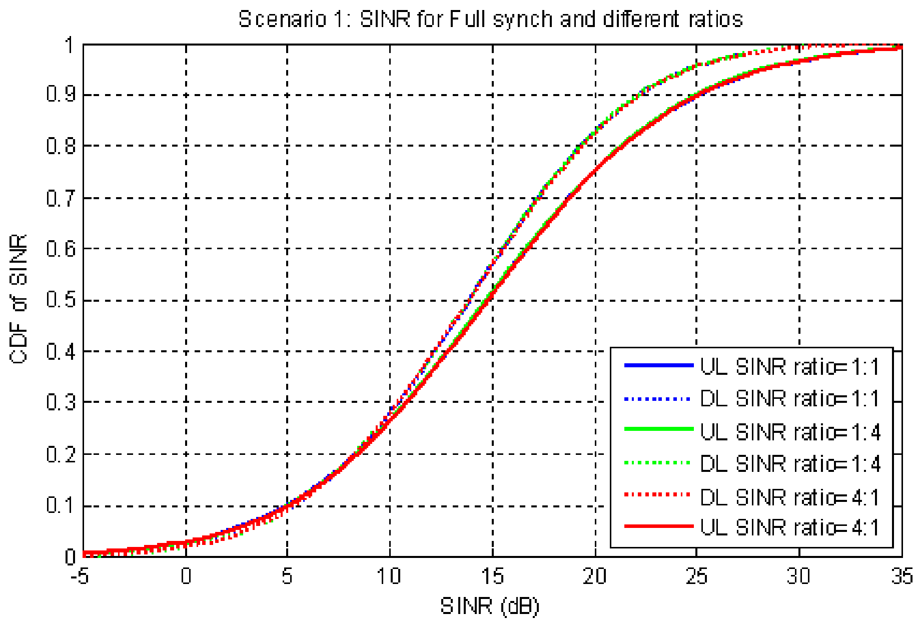

Figure 4.2: Scenario 1, Full synchronization

The above figure shows the behavior of the system when it is fully synchronized.

With full synchronization and UL/DL ratio fixed to be the same for both cells, UL/DL is perfectly aligned so, interference comes just from UEs to Access Point links. As explained in Section 3.1.

For DL transmission, when UL/DL is perfectly aligned, interference comes from the access point in the adjacent cell to UE links while for UL transmission, interference comes from adjacent UEs to the access point.

The level of interference received in both UL and DL is very similar; anyway in this scenario the UL SINR is better than DL SINR because the transmitted power of the BS to one MS is lower than the power transmitted by the MS since the BS needs to support more bandwidth manage the transmission for all users simultaneously. Anyway, in the bottom of the graph UL and DL have the same SINR because when the MS are far from the BS the power of the interferences received from the other MS are more similar to the main signal power. Then, the UL performance becomes worse.

As was said before, the interferences are not between UL and DL because they are aligned (full synchronized), so the shape of the curves is the same for all ratios.

Loose synchronization

The following graph shows the behavior of the system when there is loose synchronization.

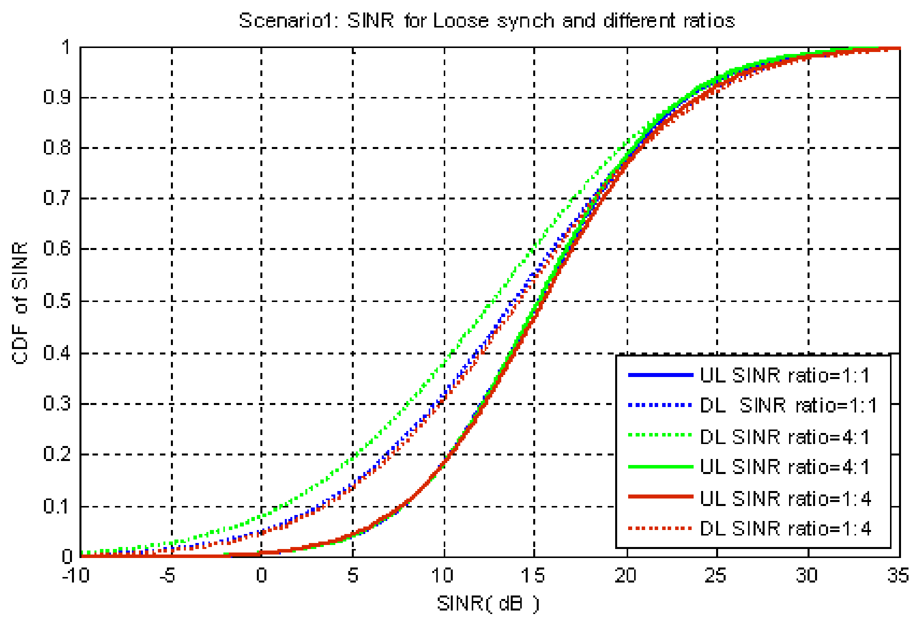

Figure 4.3: Scenario 1, Loose synchronization

The three representations plotted for different ratios have he same shape and the values of them are very similar. When the SINR is low (bottom of the graph) UL and DL are separated and UL is always higher than DL SINR. For example, for ratio=1 UL is less than 10 dB 20% of the times while DL is less than 10 dB 30% of the times. It is due to the fact the transmitted power from the BS to the MS (DL) is lower than the transmitted power from the MS to the BS because BSs have to support more bandwidth and the power is affected. So, the SINR for UL is higher than the SINR for DL.

Then, when the SINR values are higher (top of the graph) the DL and UL curves are overlapped. This is because when synchronization is perfect (the synchronization is not always lost) UL and DL SINR values are more or less the same as in the full synchronization case. The main difference is that in full synchronized case UL curves and DL curves are overlapped on the bottom of the graph ,and here they are not. It is because the interference due to UL are not affected for the inteferences due to the lost of synchronization.For this kind of cell, MS's from adjacent cell interfere more to the BS (MS to BS interferences) than the adjacent BS intefere to the BS when the system is not fully synchronized (BS to BS interferences).

In loose synchronization case, DL curves of different ratios are not overlapped. The only difference between the different ratios is that when the ratio increases DL SINR gets a little bit worse. The reason is that if the ratio increases, UL has more time slots than DL so, it has more probabilities to coincide with the UL time slots for the adjacent cell. DL has less synchronization and it has more interferences coming from the other cell and the SINR will be better. The difference is very small because it is fixed on the parameter than when there is lose of synchronization it is mismatched just in one symbol and not during all the transmission.

Unsynchronization

The following figure shows the behavior of the system when it is unsynchronized for different UL/DL ratios.

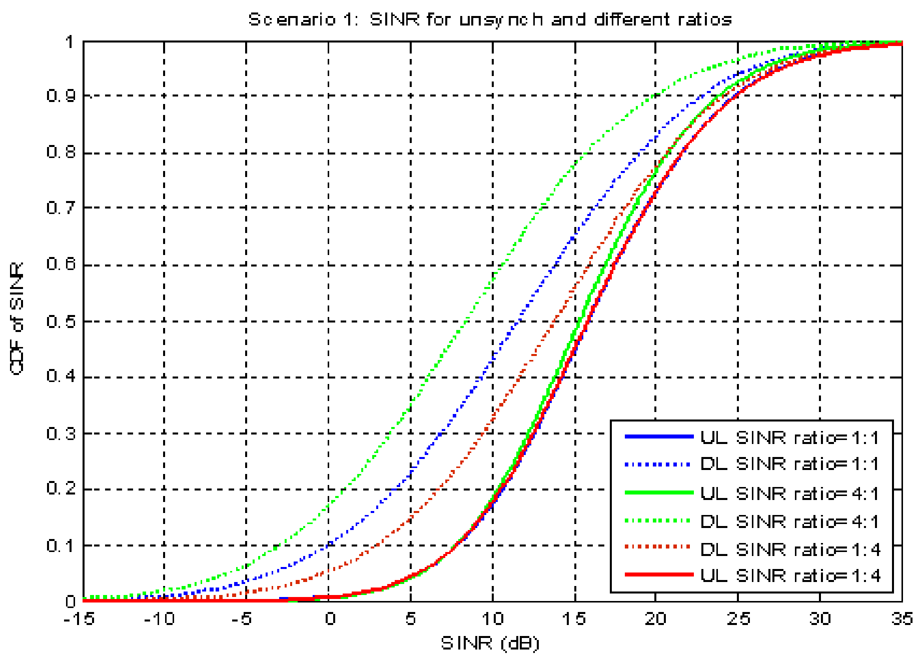

Figure 4.4: Scenario 1, Unsynchronization

In this case, the results for the three different ratios are also very similar. The UL SINR is still higher than DL SINR and the reason is the same as for the loose synch case. In this case the difference is more clear because there is no synchronization. As the ratio increases the difference between UL curve and DL curve increases too. The UL SINR is the same, but the DL SINR gets worse. It is due to the fact that DL ratio decreases and then the probability of having DL slots in one cell and DL slots in the neighboring cell at the same time decreases too. So the probability of the DL time slots to coincide with the DL slots for adjacent cell is smaller than for the UL time slots. For this kind of cell UL is not affected for the unsyncronization because there are no walls and the interferences coming from the MS belonging to adjacent cell are higher than the ones coming from the other BS. So, the MS are always interfering more in this scenario because the cells are very small and there are a lot of terminals in comparision to the size of the cell.

4.2.1.3 Study of different synchronizations

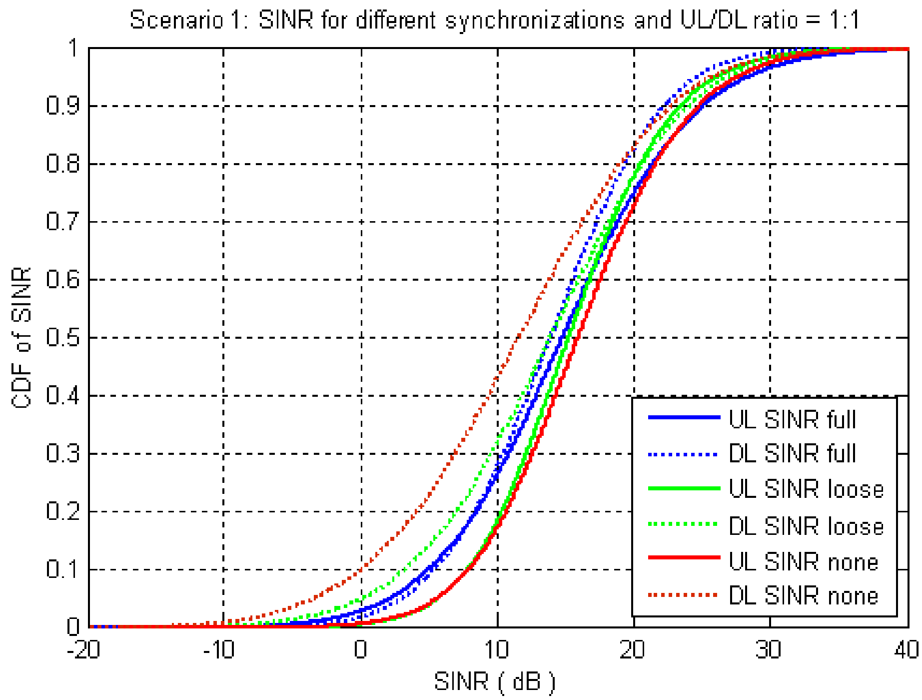

Figure 4.5: Scenario 1, UL/DL ratio =1:1

Just one graph is shown because, for different UL/DL ratios, the behavior of the SINR is very similar. The only difference is that, when the ratio increases, the separation between the different curves of the same synchronization type increases too. It is because DL SINR gets worse as we increase the UL ratio. The cause is that, the probability to coincide DL time slot with DL time slot for the adjacent cell is smaller. This is the reason why for Full synchronization case there is no difference when ratios change.

In general, and for all ratios, UL none synch is the best for low SINR (one on the bottom of the graph) while the DL none synchronization is the worst. Then, on the top of the graph, the UL full synchronization is always the best one. It is because, when it is full synchronized, the UL interferences are just from MS to BS so it will be better than other synchronization cases where BS interferences are also taken into account. Finally, UL SINR is higher than DL SINR because the power transmitted for the MS to the BS is higher than the power from BS to MS since the BS has to transmitt to all users simultaneously.

4.2.2 Scenario 2: 20 rooms per square cell

4.2.2.1 Simulation condition

In this first simulation of the interferences the rooms with the base stations and the terminals have the layout of the following figure. As can be seen there are two cells with one BS and 20 small rooms for each cell. As will be shown, the large dimensions of the cells will produce some different results than for the small cells. The following study is with the same conditions that the one for the small cell, the only parameter that is different is the cell size.

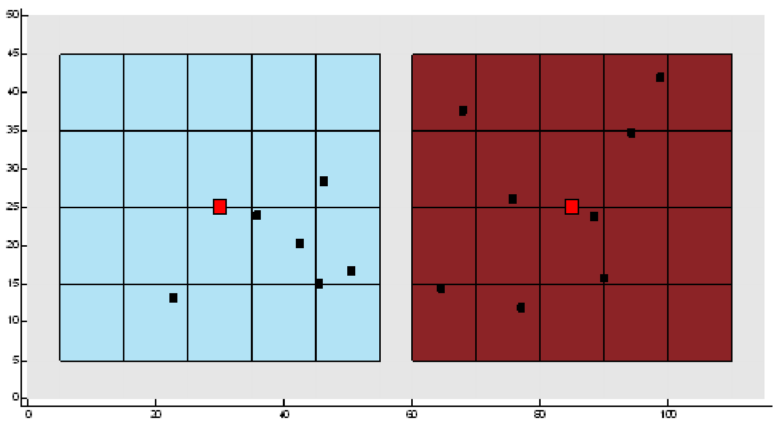

Figure 4.6: Scenario 2

4.2.2.2 Study of different ratio

Full synchronization

The following graph shows the behavior of the system when it is fully synchronized.

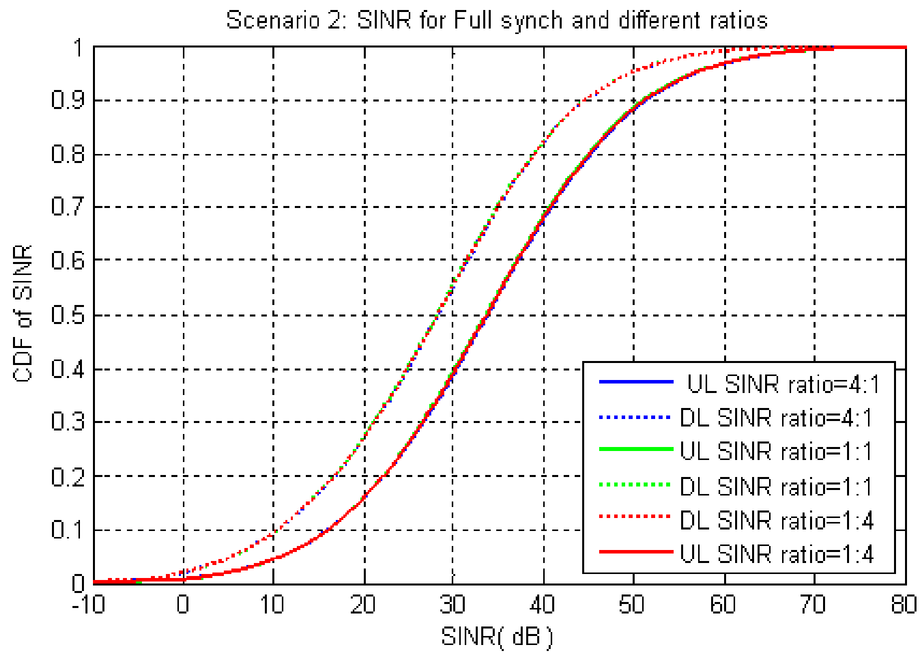

Figure 4.7: Scenario 2, Full synchronization

A big cell with full synchronization has similar performance as the small cell. As we can see, the DL SINR is still worse than the UL SINR because the interferences MS to BS are similar than the BS to MS ones but the power will be higher for UL communication. It is higher due to the fact that the BS has to support the bandwidth for all MSs, while the MS just hast to support one link bandwidth.

Loose synchronization

The following graph shows the behavior of the system when it is not fully synchronized.

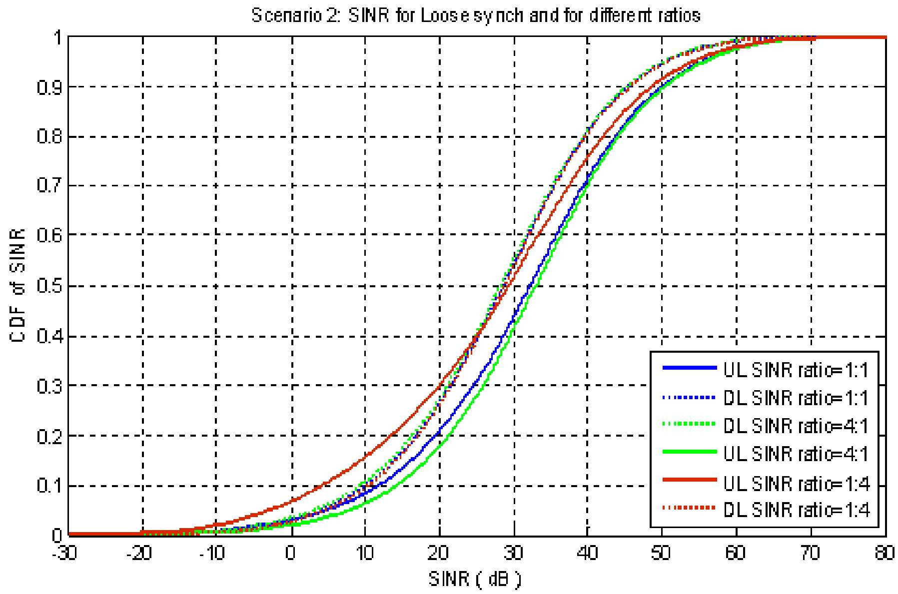

Figure 4.8: Scenario 2, Loose synchronization

In this case the SINR values are very similar to the full synchronized one because the unsynchronization is not very important, it means, there is just one slot mismatched and not during all the transmission. The difference is that, in full synchronized case, just two curves can be seen because UL curves are overlapped and DL curves too. When the synchronization is lost, the curves for different ratios are not overlapped due to the fact that the mismatched symbols affect in different measure for the different ratios.

The main interferences are form MS to BS and from Bs to MS, both of them are very similar. When ratio is 1, UL and DL have the same number of slots, anyway, for high SINR values (on the top of the graph) UL is much better than DL because, as was explained before the BS has to manage the transmission to all users.

As the ratio increases, the two curves are more separated. The main difference is on the bottom of the graph when the SINR values are low. In this part, UL gets better as the ratio increases. It is because UL has more slots than DL and the UL slots coincide more times, then the interference is lower. When ratio is lower than 1, UL SINR gets worst (on the bottom of the graph) and the reason for that is that, DL has better synchronization than UL.

Unsynchronization

The following graph shows the behavior of the system when it is unsynchronized.

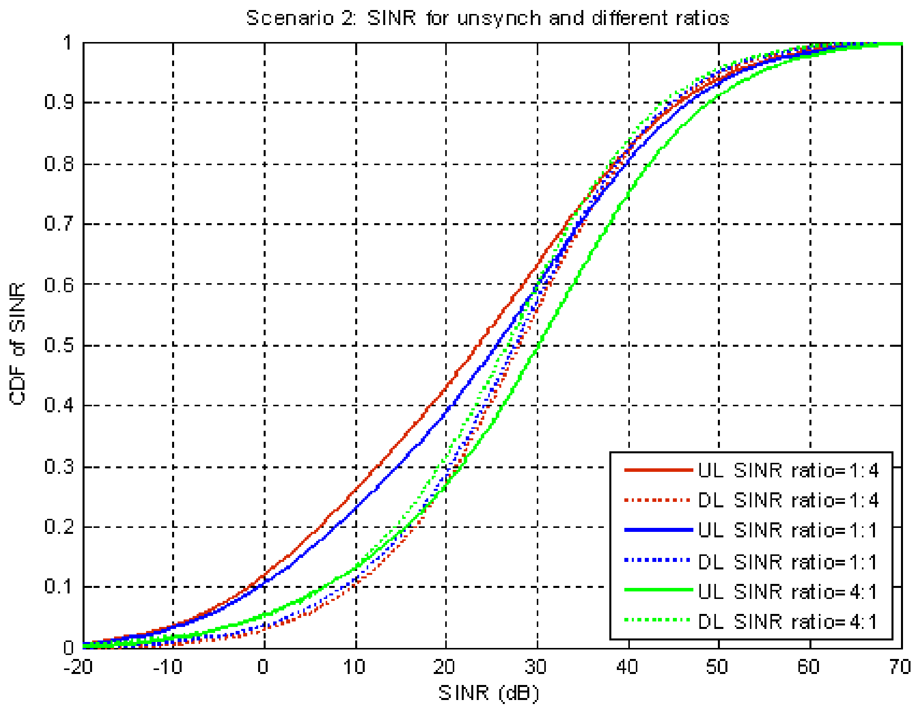

Figure 4.9: Scenario 2, Unsynchronization

If the UL/DL ratio is 1:4 DL has more time slots than UL. For this reason probability of having both cells in DL transmision is higher so, the DL interference is lower. This is why for low ratio values DL SINR is much bigger than UL SINR on the bottom of the graph. Then, on the top of the graph UL and DL curves are more overlapped, it is because it takes place when the synchronization is better and the differences between UL and DL interferences are smaller. Anyway, on the top of the graph, as the UL /DL ratio increases UL SINR and DL SINR are more separated, it is because UL is better synchronized and its behaviour improves. (as was explained in the other cases).

With ratio equal 1, UL and DL have the same amount of traffic. The difference between them on the bottom of the graph is because the interferences from the adjacent cell when there is none synchronization affect more the UL. The reason is that UL is affected for the BS to BS interferences, that are higher in this scenario because the cell is bigger than in the scenario 1 and has more rooms. DL curves are overlapped while UL curves are different. This is completely different than in the first scenario because, now, there is more walls. In this case the BS interferes more to the next cell than the other MS's. When there is none synchronization BS interferes the UL transmission, this is why in this case UL varies and DL is constant for the different ratios.

4.2.3 Scenario 3: 20 rooms per rectangular cell.

This scenario has same dimensions and performance as Scenario2, the only difference is in cells distribution. As can be seen in Figure 4.10 ,in this case the BS's are in the corridor because of the rectangular form of cells. In figure 4.12 is shown the SINR for this scenario when ratio is 1:1 and for different synchronizations.

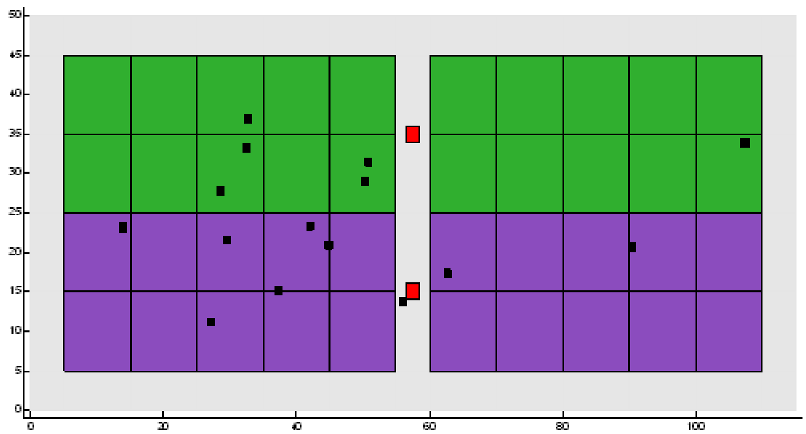

Figure 4.10: Scenario 3

4.2.4 Comparision between Scenario 1 and Scenario 2

There are some differences between small cell and big cell. In our scenario, when the cell is bigger the SINR use to be better. The reason is that, when the cell is small, there are no walls inside the cell, so the interferences from adjacent cell have less path loss and interfere more to our signal.

For Scenario 2, when the system is fully synchronized, the separation between UL curve and DL curve is bigger, it can be seen clearly when MS are far from BS (bottom of the graph). Since big cell (Scenario2) has also more walls than small cell (Scenario1), UL and DL SINR will be more diferenciated when the MS's are far from the BS. So, BS needs to transmitt to all users simultaneously and if the cell is big the DL SINR is getting worse because the signal also needs to go through the walls.

If the system has loose synchronization and the cell is big, there is more separation between UL curves, while if the cell is small there is more separation between DL curves. The loose synchronization results in BS to BS interferences and MS to MS interferences. If the cell is small the MSs will be very close, so these DL interferences will be really high and in this case they will change more when the ratio is different. If the cell is big, the BS to BS interference becomes more important than the other one so the UL SINR will changes more for the different ratios.

Finally, when the system is unsynchronized, the behavior referring to the separation between DL curves for small cell and between UL curves for big cell is the same. In this case the difference is that, for the big cell, the UL SINR is worse than the DL SINR. The reason is that, for the big cell, the BS to BS interference is worse than the MS to MS interference and the UL results more damaged when it is not synchronized.

4.2.5 Comparision between Scenario 2 and Scenario 3

For the comparision between Scenario 2 and 3 we have focused in the case that UL and DL have the same bandwith, so UL/DL ratio =1. The figures 4.11 and 4.12. are for scenario 2 and 3 respectively.

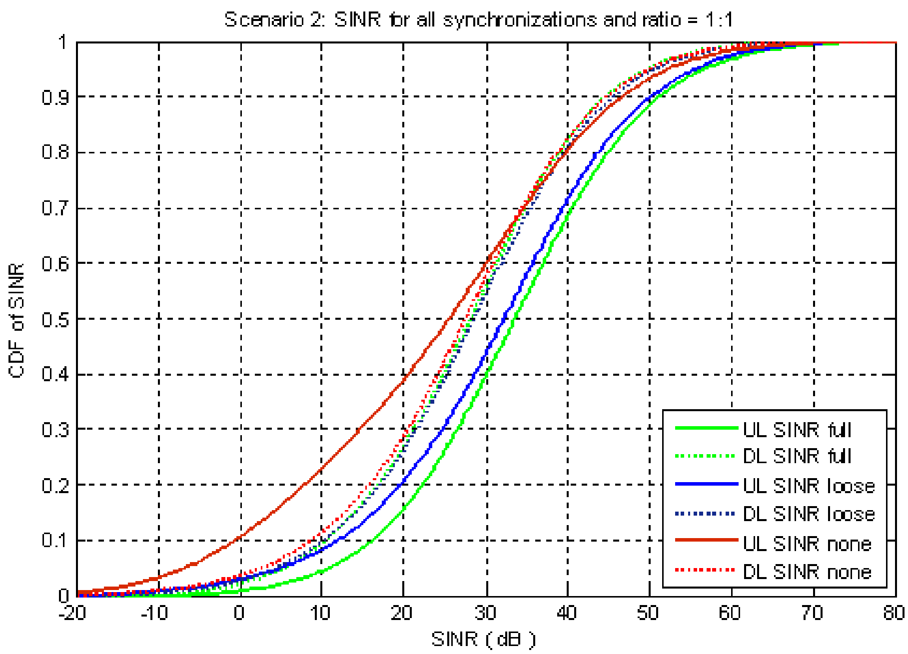

Figure 4.11: Scenario 2 for ratio =1:1

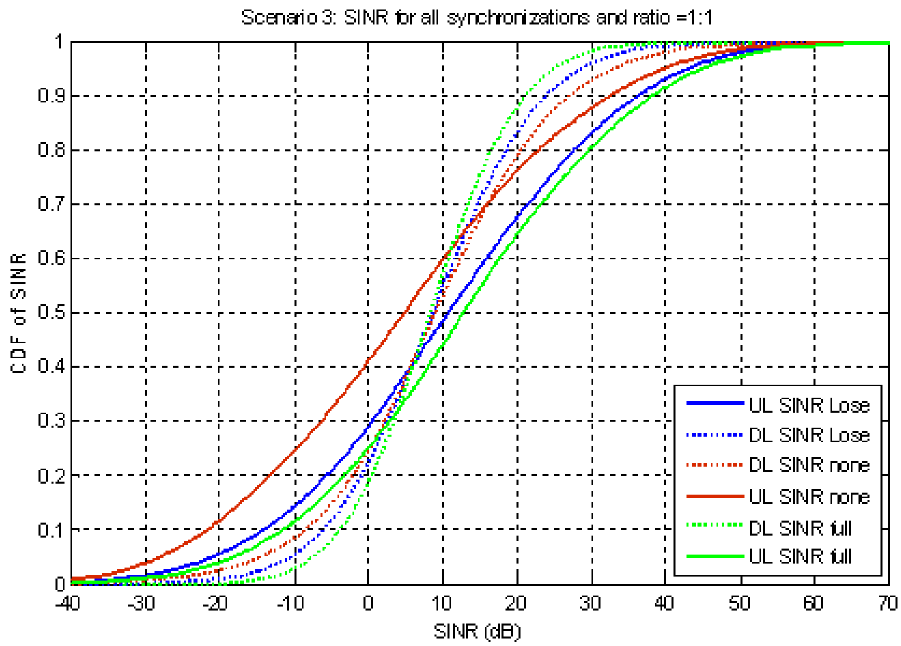

Figure 4.12: Scenario 3 for ratio =1:1

Comparing both scenarios can be seen that in UL the unsynchronization case is always worse than the other two, but in DL it changes. For squared scenario, different DL SNIR are very similar between them. In the case of rectangular scenario, for lower values of SINR, full is the best case but when SINR gets higher values unsynchroniation case is the best one. It is because the higher values are for the users near the BS. When there is full synchronization and DL, the interferences are between BS and MS and, as we can see in the layout, the two BS are very close and there is no wall between them. So, the BS will interfere a lot to the MS belonging to the adjacent BS. This is why full is worse than none synchronized case. If it is none synchronized in DL, the interferences are MS to MS and they are not as big as the other ones because in general they are more separated.

In the last two scenarios we can see clearly that the square one is really better than the rectangular one. It is because the cells are more symmetrical and, in general, users receive better signal. In the first squared one, for the worse case, the signal has to go trough three walls and in the best case it dont has to go through any wall. Concerning rectangular one, for the worse case, the signal has to go through five walls and in the best case one wall.

4.2.6 Conclusion

After a comparision between three scenarios we decided to use the second one since it has better performance. For this particular case, the scenario with smaller cells and less obstacles doesn't present the best behaviour. We just show that in this case the interferences are also higher and it damages more our singal than for the other cases. So, we conclude that the walls are an obstruction for the singal but are a bigger obstruction for the interferences coming from the adjacent cell.

It is aslo shown that with the same layout is better to have squared cells (Scenario 2) than rectangular ones (Scenario 3). The system has better performance when the MS are spread in a square cell with the BS in the middle than when it is not a regular one. It is due to the fact that in the worst case they have more walls to cross and also because there is a corridor inside the cell. So more attenuation and no corridor between a cell and its adjacent one realays in more interferences.

4.3 Sorting Approach & Power Control simulations

In order to minimize the interference effects and improve the signal reception, SA is applied. The aim is to allocate each UE's sub carriers (PRBs) in the most favourable zone inside the interference spectrum according to a specific parameter described below. Also PC is considered in the simulations in order to check the benefits that could provide to SINR.

As it was explained previously, SA lies in the allocation of PRBs from different UEs belonging to each cell inside interference spectrum in a specific way. For this project, the criterion followed for the allocation is perform it according to the ratio between the link pathloss corresponding to the cells BS and links pathloss corresponding to the BS from the adjacent cells. On this way, a measurement of link's quality for all UE belonging to a cell is obtained.

Power Control algorithm calculates individual power corresponding to the transmitter element in function of the pathloss for the link and the SINR wanted to reach. In order to perform this calculation Equation3.1 is used.

The algorithm implemented checks if the power calculated goes beyond any of the power limits, performing a normalization to the closest threshold in that case.

First of all, in order to set the starting point for the evaluations, a first SINR sample with SA and PC disabled is obtained. The profile of CDF performance is showed in Figure 4.13.

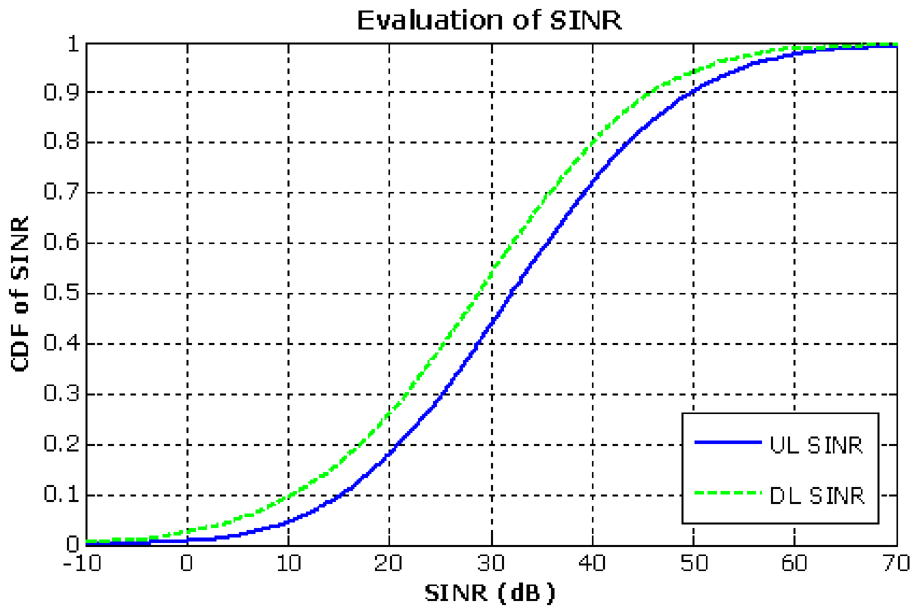

Figure 4.13: Initial simulation SINR profile

In the following, this is the original evaluation which is compared with the different profiles of SINR considering the different mechanisms implemented.

4.3.1 Initial evaluation compared with SA Evaluation.

In Figure 4.14 is showed the comparison between the original SINR for uplink and downlink and the simulation with SA is implemented.

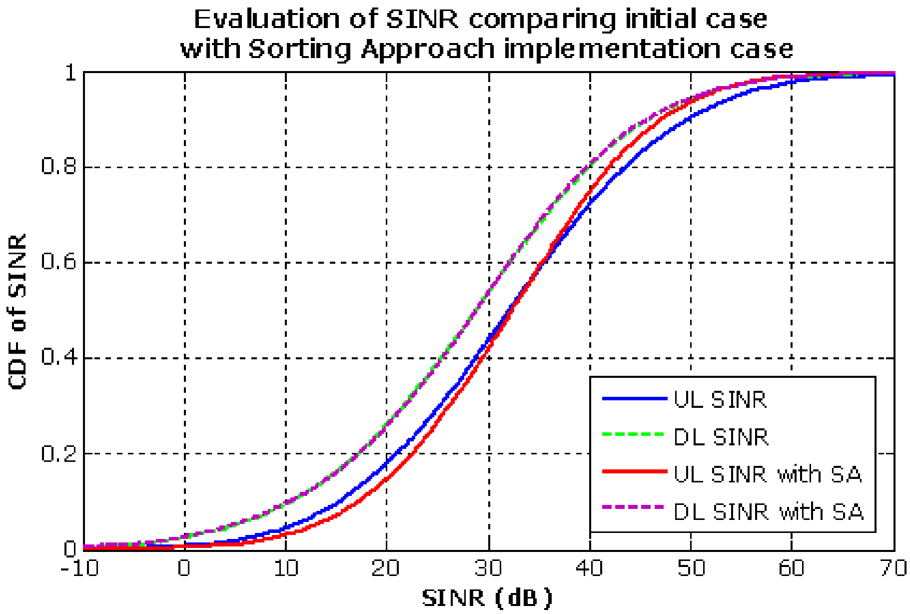

Figure 4.14: Initial evaluation compared with SA Evaluation.

It can be seen that, the implementation of SA, produces a change in the level of SINR for uplink case at the same time that downlink curves keep invariable and matches one to each other. For uplink, the best level of SINR decrease around 4 dB in the maximum and, in the lower part of the curve, a benefit of around 3 dB is obtained.

As it was previously explained, SA allocates in the same part of spectrum the PRBs of UEs belonging to different cells, and with highest difference in path loss levels between them that is possible. For that reason, users from different cells with low pathloss that were randomly assigned to the same portion of spectrum are now reallocated.

This new order in the spectrum assignment produces asymmetrical path loss allocation for the UEs that are emmiting and receiving in the same bandwidth. This, together with the fact that all users are emitting with same amount of power (maximum power limit), produces that the interference received in each user gets compensated. All this gives the reason of the behaviour for uplink curve with SA implemented.

Concerning the downlink curve, the result with no variation is due to the fact that the BSs are emitting exactly with same power for all spectrum. So, even if sorting approach is considered, the omnidirectional transmission does not produce any modification in the interference received by the UEs.

4.3.2 Initial evaluation compared with SA Evaluation.

This simulation is performed in order to check the impact that the use of power control has in the results. In Figure 4.15, the comparison between initial simulation and the results obtained with power control implementation is performed,

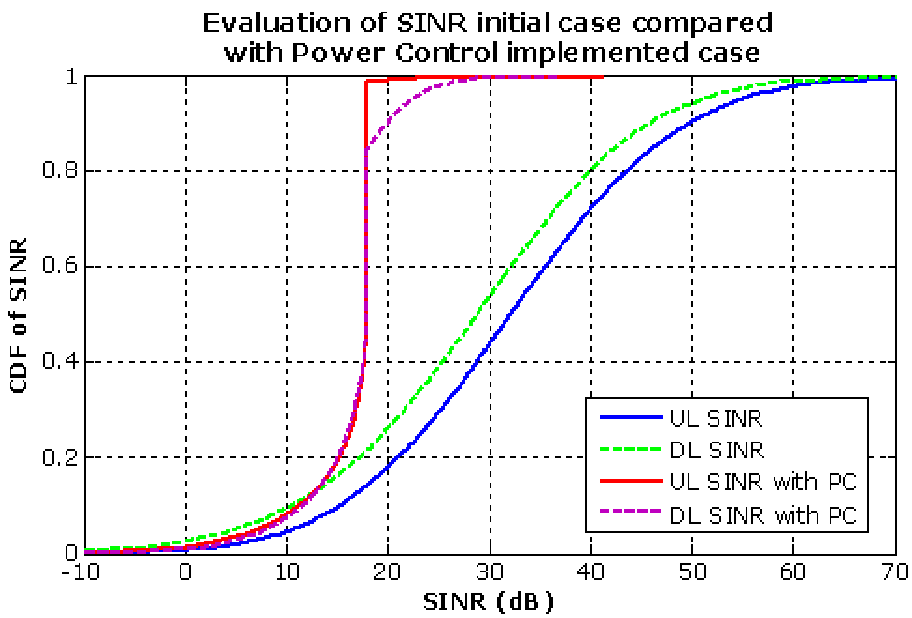

Figure 4.15: Initial evaluation compared with SA Evaluation.Initial evaluation compared with PC Evaluation.

As it was explained before, power control implementation performs a manage of the power emitted by each MS or BS depending on the particular path loss for each link. In the previous case, all elements were emitting with maximum power allowed for UL and DL but, now, the transmission power has been reduced for most of them due to the new power calculation algorithm. It explains the high level of losses SINR for both links.

For UL and DL curves, power control implementation increases a lot of losses in the signal along SINR curves.

4.3.3 Initial evaluation compared with SA and PC enabled Evaluation.

In Figure 4.16, different results obtained for the implementation of SA and PC are showed,

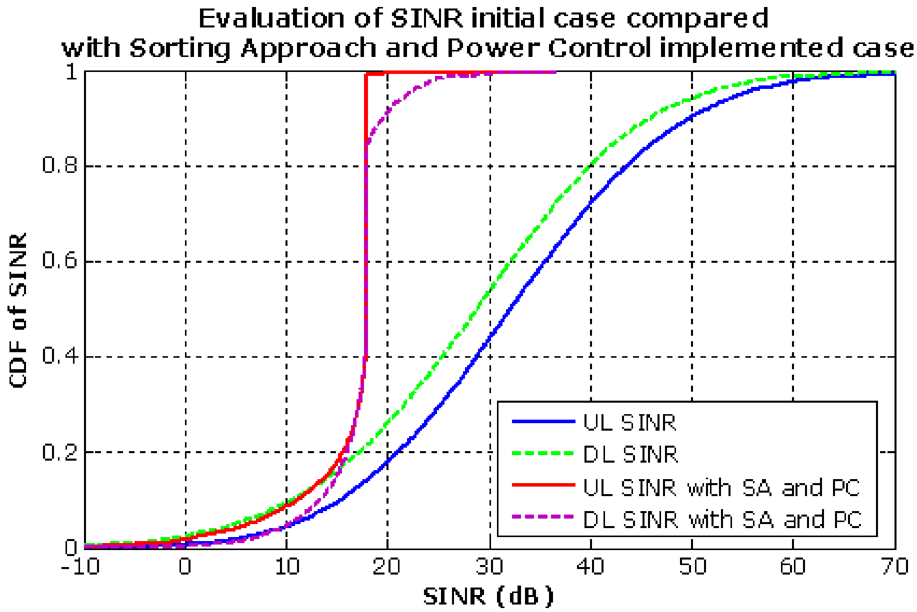

Figure 4.16: Initial evaluation compared with SA and PC enabled Evaluation.

For uplink curve, high levels of losses can be appreciated. Here the signal loses around 27 dB in its highest level. The worsening of the SINR is very showed off.

Due to fact that PC is used in this evaluation, SINR presents loses in the same way as the previous simulation. In this case, couples of MSs which share same spectrum zone are now using different amounts of power due to their different path loss.

In the case where PC was not implemented, all MSs were emitting with maximum power allowed, but now the transmission power has been reduced for most of them. Also is crucial take into account that the parameters used for the allocation of the users in the spectrum and for the calculation of power are different.

On one hand, the parameter considered to put, in order the PRBs of the users in the interference spectrum, is the ratio of the path loss for the information link over the path loss of the interference link.

On the other hand, power calculated for each MS is only function of the particular path loss of the information link. This makes the order of users allocation does not match with the different levels of power from the MSs and it affects negatively the level of signal that base station is receiving from users.

In another way, DL gets benefits of the combined use of SA and PC, the users with low SINR improves the signal between 0 and 4 dB. This benefit is due to the fact of combining the adaptation of the power transmitted for each user with SA. With this method, users situated very close physically are not allow the be allocated in the same part of the spectrum.

What attracts our attention is the fact that the decrease of this part of the curve is very high, around 30 dB in the worst case. This is due to the target SNR chosen for the calculation of power in the power control algorithm.

4.3.4 Synchronization parameter simulation

The variation of synchronization parameter introduced in point 4.2 is considered in the following simulation. Due to the results obtained previously, the implementation of SA in UL and DL transmission and also PC for DL is considered as the starting point.

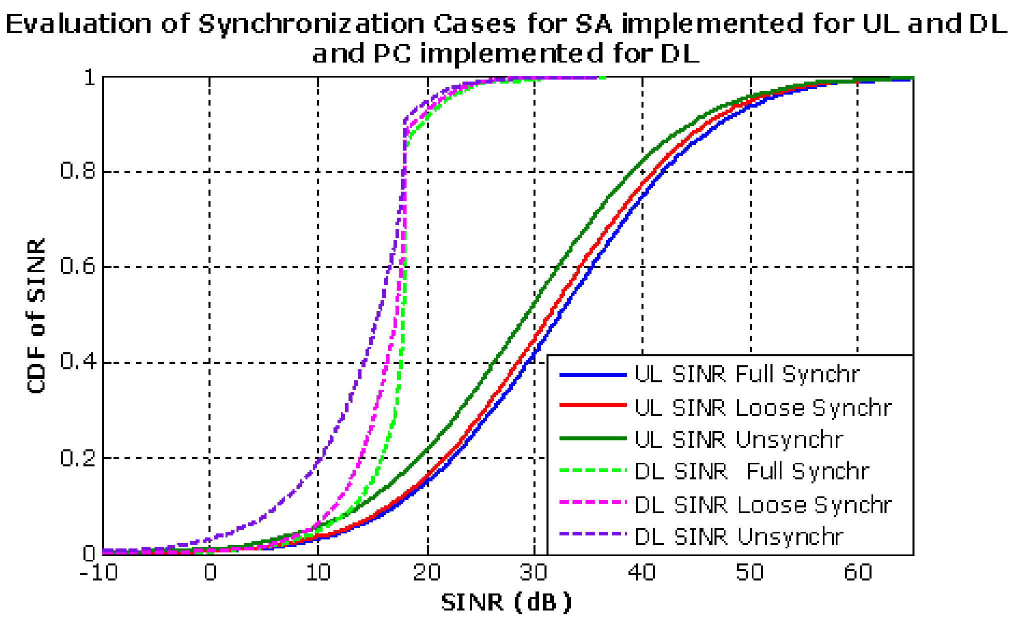

Figure 4.17: Different types of synchronization for the case where UL has been implemented with SA and the DL with SA and PCS

As is showed, for uplink case, the increase in the loss of synchronization causes an obvious worsening in the level of the signal along all the curve. This is due to mismatch between transmission profile in time domain belonging to different cells, that causes interferences in certain percentage of the bandwidth. These interferences causes less level of signal in the bandwidth set for UL, and this fact translate into losses in the final SINR obtained.

For downlink curves, equivalent losses can be seen for the users with low gain, situated in the lower position in the curve. The principle that works here is the same previously exposed for the UL, and the deterioration of the SINR increase together with the level of synchronization losses. Due to the limitation caused by the choose SNR target in power calculation (18 dB), the progressive lose of SINR can not be appreciated until the top of the curve.

4.3.5 Conclusions

Refering to performed evaluations, some features for the mechanisms implemented can be studied. In the case of UL, certain improvement in the response has been obtained using the implementation only with SA. As it was explained before, this is due to constant power used for the users allocated inside the same bandwidth together with the reallocation for PRBs using SA. Using UL with PC makes the curve get a lot of losses,due to the fact that the parameters used to make the allocation are not the same as the parameters used to calculate the power.

Concerning the DL, it gets better results when SA and PC are enabled. A combination of both of them is necessary in order to reach a benefit. For the SNR target chosen for this scenario, the DL presents improvement only in a limited region in the low part of its SINR profile.

The evaluation with synchronization parameters shows a decrease in the quality of signal comparable to the evaluations without SA and PC due to the interference level introduced by the loose of synchronization.

4.4 Effective SIR Mapping Simulation

In the simulator and for Scenario 2, $SIR_{eff}$is calculated and compared with SIR in order to find the possible effects caused by the mapping of the effective SIR value to the SIR_{eff}.

Different parameters, such as MCS , types of synchronization, number of users and up-down ratio have been changed in order to study all the effects added by the implementation of effective SIR in downlink

4.4.1 Study of different MCS

Simulations have been carried out for two different modulations schemes (QPSK and 16QAM) and two different code rates for each modulation scheme ($R = \frac{1}{3}$ for QPSK; $R = \frac{2}{3}$ and ; $R = \frac{4}{5}$ for 16QAM).

According with the table 3.1 it is easy to associate the parameter beta with several modulations schemes and code rates.

- Beta= 1.49 QPSK with code rate of $\frac{1}{3}$
- Beta = 3.36 16QAM with code rate of $\frac{1}{3}$
- Beta=7.68 16QAM with code rate of $\frac{4}{5}$

In order to evaluate the performance according to different MCS, the number of users has been fixed to 5 and the ratio considered will be 1:1

Full synchronization

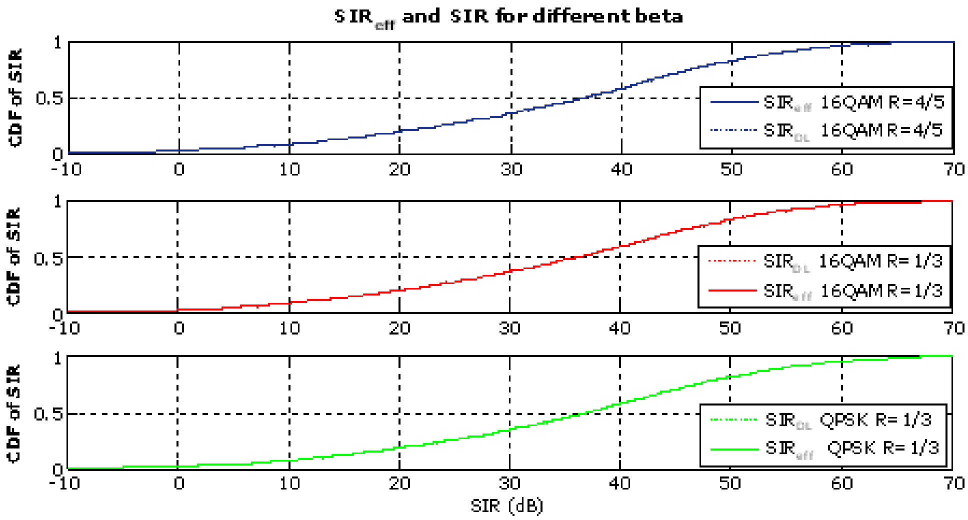

Figure 4.18: SIR effective and SIR performance for full synchronization, ratio 1:1 and 5 users per cell

Loose synchronization

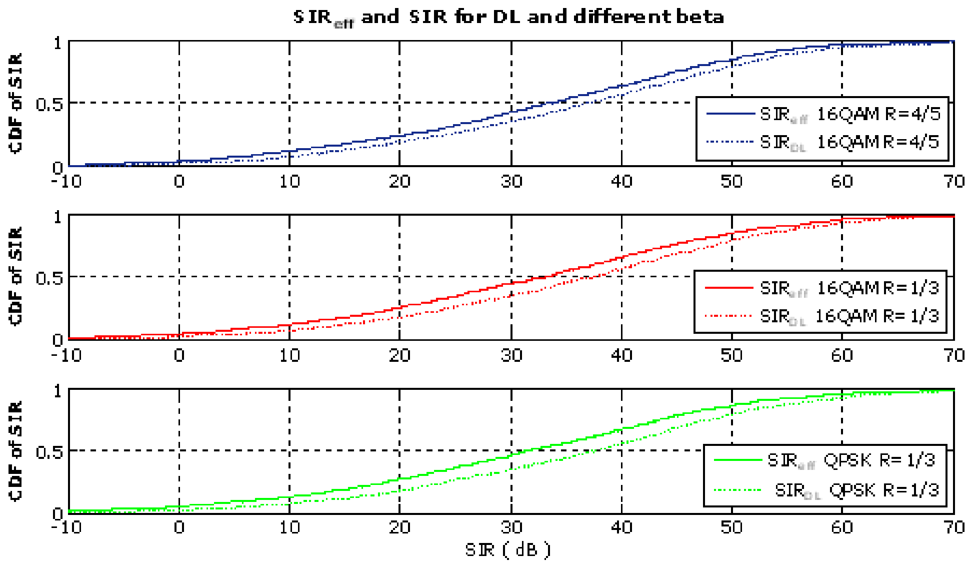

Figure 4.19: SIR effective and SIR performance for loose synchronization, ratio 1:1 and 5 users per cell

Unsynchronization

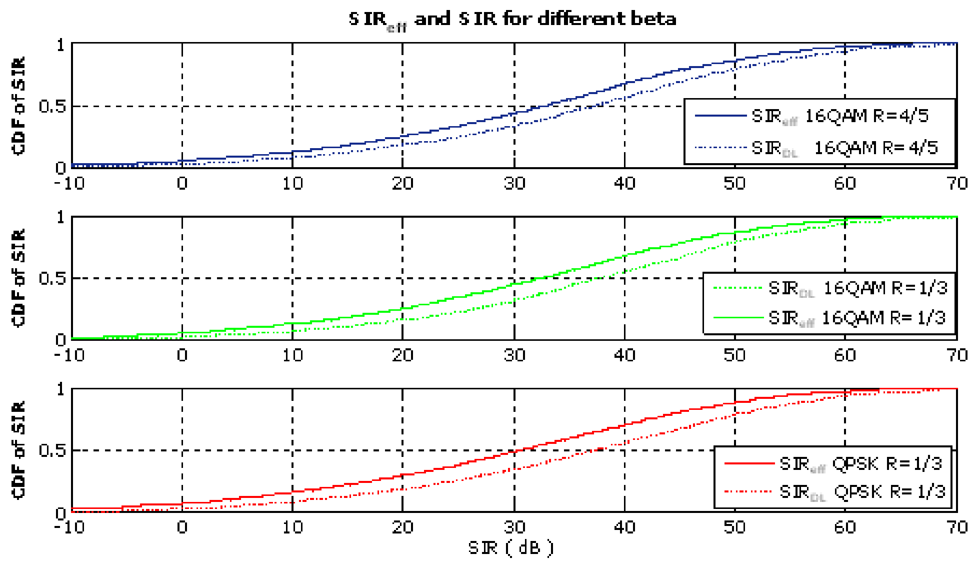

Figure 4.20: SIR effective and SIR performance for unsynchronization, ratio 1:1 and 5 users per cell

Figure 4.18, Figure 4.19 and Figure 4.20 show the effective SIR and SIR distribution for DL in the case of three different synchronizations and for three different value of the parameter beta. As can be seen, there is an higher level of effective SIR for each of the synchonization modes as the value of the parameter beta increases. That means that the best effective SIR is obtained for 16QAM R=$\frac{4}{5}$ as well as R=$\frac{1}{3}$ and the worst one for QPSK R=$\frac{1}{3}$ modulation because of QPSK is more robust than 16QAM, while 16QAM gives better throughput. The same behaviour is show for SIR for the cases of loose and none synchronization.

Regarding full synchronization, there is an extremely good match for each of the both SIR curves and modulations. Like the synchronization is perfect, SIR for each user is the same so that SIR and effective SIR match perfectly, regardless of modulation and code rate because accoding to Formula 3.11 the effective SIR calculated from SIR results to be the same although parameter beta changes.

4.4.2 Study of different ratio

Now, the impact of different ratio will be studied. For that purpose, the MCS chose is 16QAM with code rate 1/3 and the 5 users per cell.

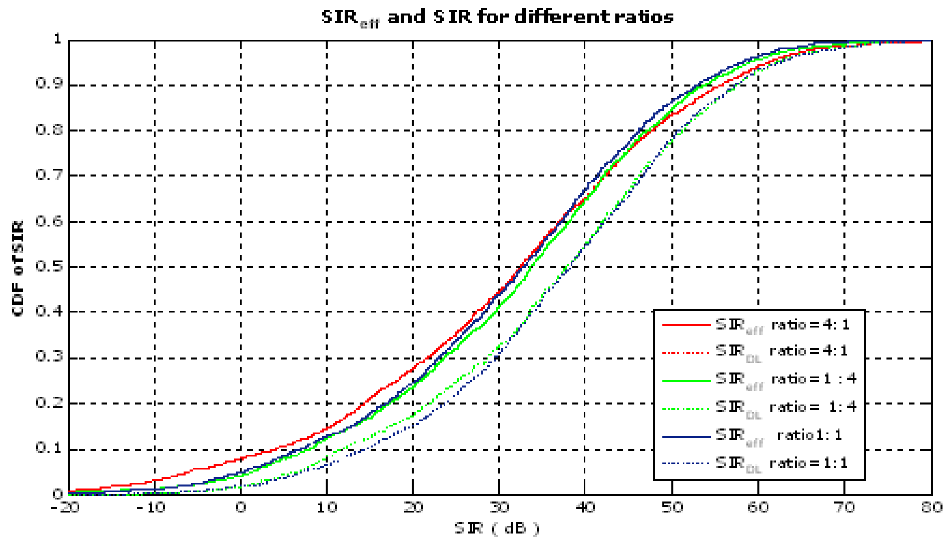

Figure 4.21: SIR effective and SIR performance for unsynchronization, 5 users per cell and beta=3.36

Figure 4.21 shows the difference betwen SIR and effective SIR for different ratios in the case of none synchronization.

It is shown that there is a difference about 5 dB between SIR and effective SIR. This big difference is due to since the SIR for each PRB will be different now, these PRBs which do not have a lot of interference. Hence the corresponding SIR values will be high so the difference between both values SIR and SIR_{eff}will be higher whenever we calculate the negative exponencial for calculate the SIR_{eff}..

Regarding the ratio, it is appreciable a difference about 2 dB between the best and worst case, that is ratio 1:4 and 4:1 respectively. Like we are considering DL transmission, if the ratio is 4:1 the DL slots could mis-match easily since there is less number of slots than for UL so the SIR level becomes lower.

4.4.3 Study of different synchronization

In order to verify the behavior of three types of synchronization for both the higher and lower MCS considered before, this time the ratio will be fixed to 1:1 and 5 users per cell will be considered.

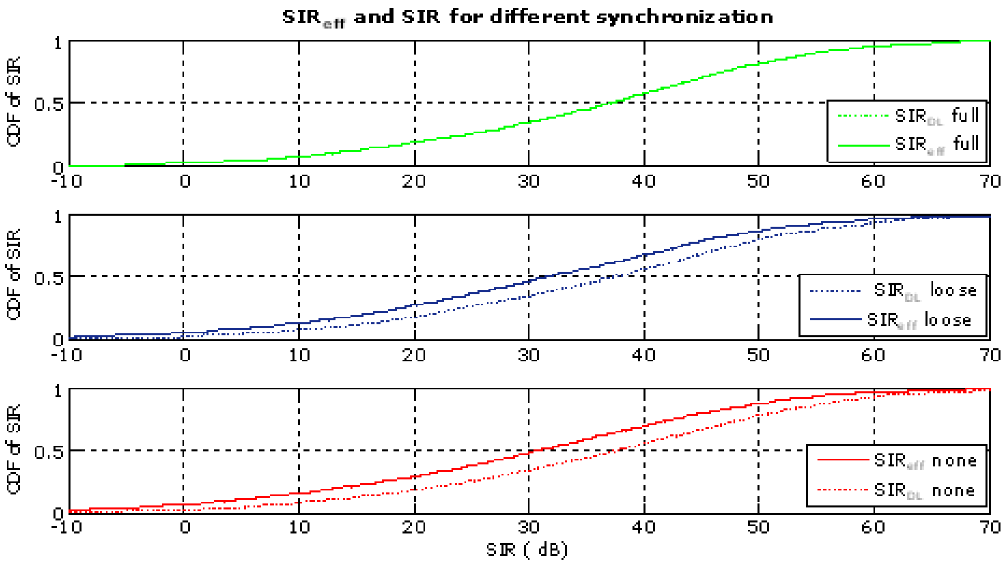

Figure 4.22: SIR effective and SIR performance for beta=1.49 , 5 users per cell and ratio 1:1

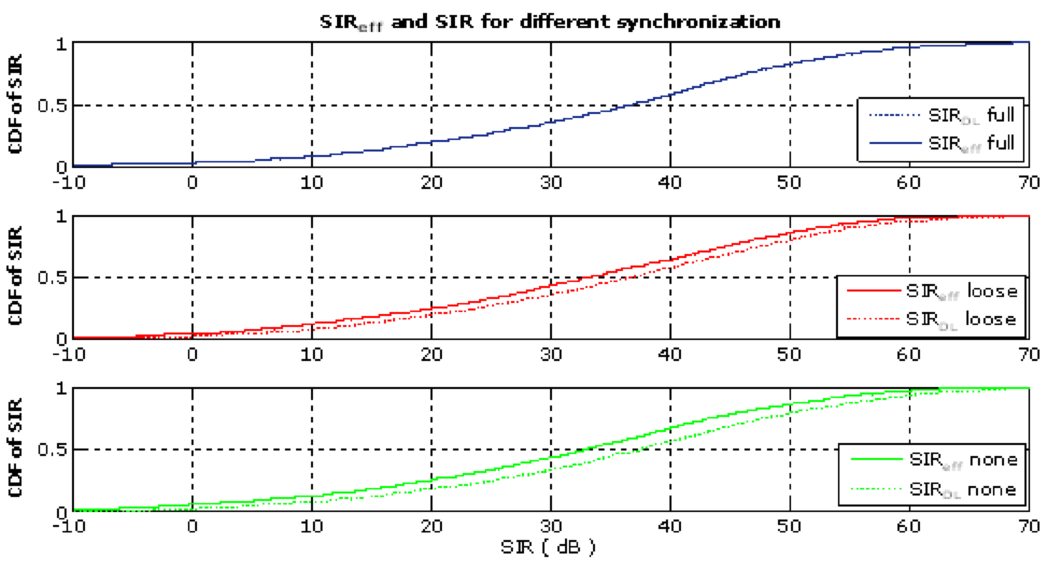

Figure 4.23: SIR effective and SIR performance for beta=7.68 , 5 users per cell and ratio 1:1

Figure 4.23 and Figure 4.22 show the effective SIR and SIR distribution for DL in the case of three different synchronizations and for two different value of the parameter beta. As can be seen, there is a higher level of both SIR and SIR effective for the last case, that is 16QAM with $R = \frac{4}{5}$, which is comprehensible due to this modulation has a better throughput than QPSK as has been explained before.

4.4.4 Study of different number of users per cell

Now, the influence of randomly (between 5 and 10) number of users per apartment will be studied. The MCS will be 16QAM with $R = \frac{4}{5}$, and ratio 1:1.

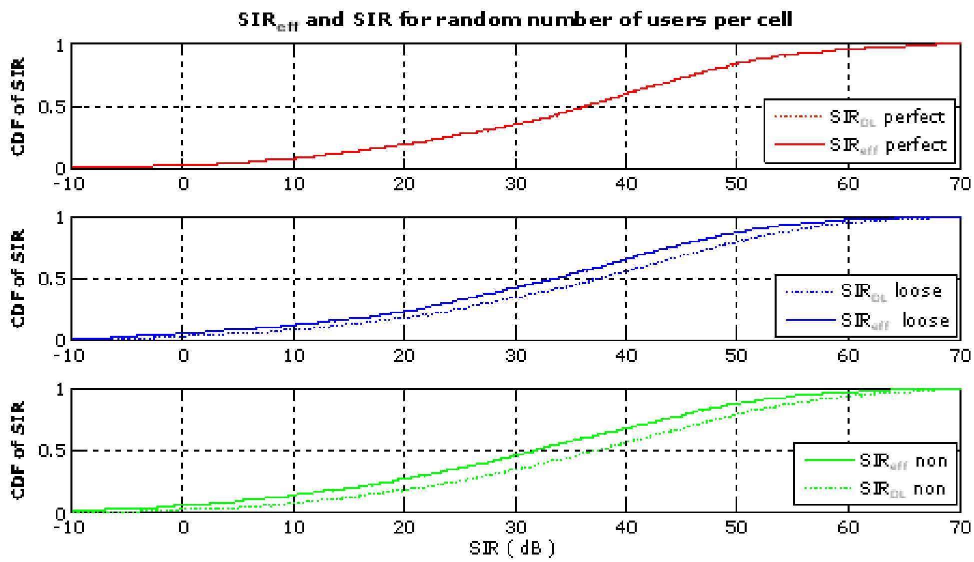

Figure 4.24: SIR effective and SIR performance for beta=7.68 , 5 to 10 users per cell and ratio 1:1

Figure 4.24 shows the influence of randomly (between 5 and 10) number of users per apartment. As was expected, DL SINR and effective SIR match perfectly in the case of full synchronization. Like the ratio is 1:1, the interference comes from only the BS hence the interference is the same from PRB to PRB and the performance for both cases is the same. The same procedure can be applied to the loose and no synchronization cases to understand its behaviour as is explained before in the study of different ratio.

4.4.5 Study of different synchronization for UL

In order to verify the higher degradations for OFDM for UL comparing with SC-FDMA, some parameters will be fixed and the three different types of synchronization will be shown.

The MCS will be 16QAM $R = \frac{1}{3}$, ratio 1:1 and number of users fixed to 5.

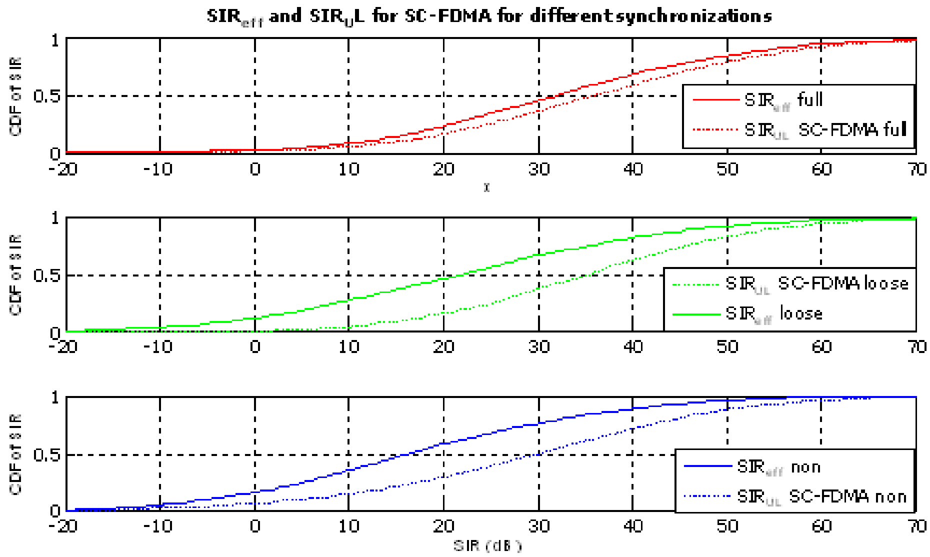

Figure 4.25: SIR effective and SC-FDMA SIR performance for beta=3.36 , 5 users per cell and ratio 1:1

4.4.6 Conclusions

In order to deal with accurate system-level evaluations, new method for calculating SIR has been proposed. A comparison between both SIR and effective SIR for downlink has been evaluated. As a general trend, the EESM method leads to lower SIR results compared with SIR especially when the system is unsynchronized. Nevertheless this gap is reduced as the MCS order increases due to the higher the modulation order is, the more throughput offers to the system. In the LA scenario considered, no significative difference have been noticed among the loose and no synchronization, due to one mis-match slot is sufficient for PRBs SIR to be different and that leads a big difference between both effective SIR and SIR. Furthermore, the impact of different ratio on performance is shown to be strong, being the ratio 4:1 the one which gives us the lower level of effective SIR.

Finally, some SIR evaluation for UL have been carrier out showing SC-FDMA performs better than OFDMA for the modulation and coding considered.

Chapter 5

Conclusions and future work

The standardization of UTRAN (UMTS Terrestrial Radio Access Network) LTE (Long Term Evolution) has started in the first half of 2005 and it will set the main reference for next generation systems assumptions[2]. As a final conclusion on the developments taking place in 2006, many of the proposed 4G solutions were based on Orthogonal Frequency Division Multiple

The selected scenario to perform this investigation consists on a wireless local area TDD indoor office environment. For this research the division duplexing is TDD instead of FDD. The main reason for using it is that it can dynamically adjust to varying trafic patterns and it is good for asymmetric communications where downlink and uplink trafic is not the same. Network synchronization in TDD-based systems is more dificult than in FDD based systems and it relies on synchronization interferences. Since reducing interference is a very important item to improve the quality of communications, to study and modulate these interferences in LA-TDD scenario have been the main aims for this project.

Three scenarios with different coverage have been studied each one composed by two cells.

After a comparison between them, SINR analysis shows that the system has better performance when the MS are spread in a square cell with more than one than when the cell is rectangular of it has only one room. And referfing to the loose of synchronization is shown that when it is not full synchronized the quality of the signal decreases.

Once the senario has been selected, certain improvement in the channel response has been obtained with the implementation of SA and PC. Sorting approach changes the way in which users are allocated in the spectum while PC algorithm assign different power to each user depending on their path loss. Concerning Sorting Approach, can be cocluded that, with the level of SNR wanted to achieve for this study, the improvement for UL transmission is only reached for the users that present a low SINR quality, also taking into account that the power used for the users is maximum for this configuration. Whereas, users with very high SINR behaviour, suffer losses regarding to the evaluation done with SA. For DL trasnmission, it has been proved that is necessary the implementation of power control in order to get that benefit, otherwise, there is not difference among the cases of implementing or not SA.

In order to approach to more realistic conditions based on system-level evaluations, EESM method to calculate effective SIR has been proposed. A comparison between both effective SIR and SIR for both DL and UL has been carried out. In order to clarify these terms, effective SIR is representative of OFDMA whereas SIR is representative of SC-FDMA. For downlink EESM method leads to lower SIR results compared with SIR especially when the system is unsynchronized. However, SC-FDMA performs better than OFDMA for the modulation and coding considered in the case of UL.

Potential investigation points for future work are:

- Multi-cell scenario modelling for inter-cell interference generation: Impact of the interference over OFDMA and SC-FDMA applying the EESM method and SA with PC.
- Beamforming: It is technique that consisting in making the signals more directional and it is achieved by using a concrete beam pattern for each antenna with a bigger gain in the desiderated direction. The implementation of this technique will provoke a considerable improvement in our system compared with the omnidirectional antenna. Thus beamforming is used to point an antenna at the signal source to reduce interference and improve communication quality.

Appendix A

Appendix

A.1 Propagation channel

Wireless channel is very unpredictable with challenging propagation situations. In an ideal wireless channel, the received signal is a reconstruction of the transmitted signal but in real radio systems, the signal would be modified during its transmission along the channel.

Experiments with mobile communication were done at Very High Frequency (VHF), near 50 MHz, already in the 1920s. Results revealed that the signal quality varied from excellent to no signal. Moving the receiver over a few meters resulted in dramatic changes of the received field strength[59].

The wireless channel is characterized by:

- Path loss
- Multipath fading
  - flat fading
  - frequency selective fading (ISI)

A.1.1 Path loss

Path loss is the quantity of energy that the signal lost during the transmission through the channel. It describes the attenuation suffered by the signal during the transmission along the channel as a function of the propagation distance and other parameters.

It is affected by several environment factors such as terrain contours (urban or rural), propagation medium (dry or moist air), the distance between transmitter and receiver, the height and location of the antennas.

It has only impact on the link budget and there are several path loss models.

A.1.2 Multipath fading

Multipath phenomenon occurs when the electromagnetic waves reach a receiver coming from several different paths from the transmitter.

Path between transmitter and receiver may be LOS or NLOS. Hence the signal that arrives to the receiver contains not only a direct LOS radio wave, but also a large number of reflected radio waves. Even worse, in urban environments, where the LOS signal is often blocked by obstacles and a collected of differently delayed waves. These reflected waves interfere with the direct wave and cause significant degradation of the performance of the link.

Since both, the length of each signal path and the arrival angle, are different, signals coming to the receiver with different time delays lead to delay spread. Delay spread is the time interval between the arrival of the LOS signal and the last multipath signal arrived to the receiver and it leads to flat fading and frequency selective fading (inter-symbol interference)

The received signal with multipath differs from the LOS received signal due to the superposition of direct signal with NLOS signals. In a multipath propagation environment, the received signal experiences fluctuation in its amplitude, phase and angle of arrival. The effect is described by the term multipath fading.

A.1.2.1 Frequency selective fading

In a digital system, delay spread can lead to Inter-Symbol Interference if the delayed signal overlaps the following symbols. Intercarrier interference is caused due to the delay of the signal received and as a result, the signal within the symbol period is not a sinusoid. In order to solve it, each symbol is cyclically extended so that the signal within the symbol period is a sinusoid.

In wireless environment, every transmission channel is time variant so channel state is likely to be different for two adjacent symbols, particularly in multipath conditions.

In narrowband signal, where the occupied bandwidth is small and the bit duration is long (low bit rates), the symbol rate is sufficiently long so that the delayed signal all arrive within the period symbol and consequently there is no ISI. However, due to multipath the entire signal (bandwidth) may vanish in a flat fade.

As data rates increase, ISI starts to appear. Whether the multipath signals are spread over multiple symbols (ISI) then they tend to massively increase the error rate.

Traditionally, this has been overcome by equalization techniques, linear predictive filters and rake receivers. This involves estimating the channel conditions. This works well if the number of symbols to be considered is low, and not only does this solve the ISI problem, it actually enhances the signal quality because even if one signal path becomes obscured the receiver can still receive energy from a different path. But as the number of simbols increase, ecualization becomes more complex for any receiver so a possible solution for solving the ISI problem at higher bit rates is the employment of OFDM.

A.1.2.2 Flat Fading

As we will explain in the next sections, multicarrier systems such a OFDM transmit multiple bits in parallel over multiple subcarriers. If delayed signals arrive within the period symbol, there will be no ISI but maybe flat fading. In that case, if one subcarrier is in fade, the other may not. Error correction coding can be used to correct bit errors on faded subcarriers.

On the other hand, whether all the multipath signals reach the receiver within the transmitted symbol, then they result in fading whereby occasionally they add destructively and no signal is received. This can be overcome by adding redundancy to the transmitted signal in the form of error-correction coding [58].

A.2 Modulations

Is a process to print the information in a high frequency signal. It is used to protect the information from the medium, to make the radiation easy and to share the medium with other signals. The modulations used to perform the ESM are QPSK and 16-QAM. Both of them are digital modulations because they are more robust against the interferences, allows to encrypt the signal and it has more spectral efficiency than the digital ones [54].

The number of bits needed for each symbol depends on the modulation used and it is calculated with the following formula:

$$Msymbols = 2^n bits \tag{A.1}$$

A.2.1 16- Quadrature Amplitude Modulation (16-QAM)

In amplitude modulations the information data is conveyed by changing the amplitude of the two waves, if one wave is the carrier the other one is the data signal. These two waves, usually sinusoids, are 90^o out of phase one with each other, hence they are called quadrature carriers[54].

In this case it is a 16 states modulation, so there will be 4 bits per symbol as can be seen in Figure A.1.

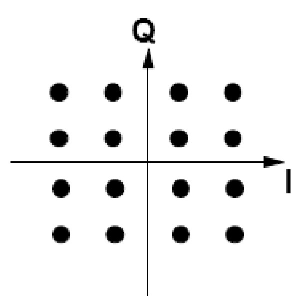

Figure A.1: 16-QAM constellation[55]

A.2.2 Binary and Quadrature Phase Shift Keying (QPSK)

The term PSK (Phased shift Keying) means that it is a phase modulation, so the information data is conveyed by changing the phase of the reference signal (carrier wave). BPSK is a two states modulation, so it has 1 bit per symbol. QPSK modulation is a multilevel modulation technique with 4 states (symbols) and 2 bits per symbol. QPSK can also be seen as a special case of QAM where the magnitude of the modulating signal is constant and the phase varies [54]. The constellations of these modulations can be seen in Figure A.2.

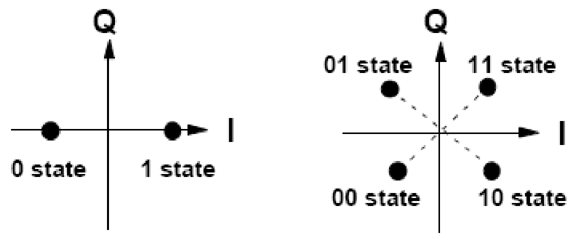

Figure A.2: QPSK constellation[55]

A.2.3 Code rates

It is the same than information rate because it let us know the total amount of useful information in our data. It is typically a fractional number (k/n) where n is the total data information and K is the bits of useful information. So it introduces n-k bits of redundancy. This extra data added will be useful for error detection but it will provoke a degradation of the system because there will be some bandwidth wasted to transport these bits.

A.2.4 Modulation coding scheme (MCS) and Link Adaptation

MCS level is the term used to specify which modulation and coding schemes are applied. For example 16-QAM modulation with 3/4 code rate. Each MCS level has a different operating range in terms of SNR, and to maximize performance the optimal MCS level should to be used with each transmission. Link Adaptation is the process of selecting an MSC level for the transmission [41].

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List of Figures

Glossary

RF Radio Frequency

FDM	Frequency Division Multiplex
TDMA	Time Division Multiple Access
CDMA	Code Division Multiple Access
LA	Local Area
MIMO	Multiple Input Multiple Output
ITU	International Telecommunications Union
LTE	Long Term Evolution
IMT-A	International Mobile Telecommunication- Advanced
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
SC-FDMA	Single Carrier- Frequency Division Multiple Access
PAPR	Peak to Average Power Ratio
ISI	Inter Symbol Interference
FDD	Frequency Duplex Division
TDD	Time Duplex Division
LAN	Local Area Network
WLAN	Wireless Local Area Network
AP	Access Point
MS	Mobile Station
BS	Base Station
UL	Up Link
DL	Down Link
SINR	Signal Interference Noise Ratio
UMTS	Universal Mobile Telecommunications System
LOS	Line Of Sight
NLOS	Non Line Of Sight
PDF	Probability Density Function
TTG	Transmit Transition Gap

RTG	Receive Transition Ga
ACI	Adjacent Channel Interference
ICI	Inter Carrier Interference
CP	Cyclic Prefix
LFDMA	Localized Frequency Division Multiple Access
IFDMA	Interleaved Interveled Frequency Division Multiple Access
DFT	Discrete Fourier Transform
CDS	Channel Dependent Scheduling
UE	User Equipment
SA	Sorting Approach
PC	Power Control
SNR	Signal Noise Ratio
SIR	Signal Interference Ratio
EESM	Exponential Effective SIR Mapping
MCS	Modulation & Coding Scheme
AWGN	Additive White Gaussian Noise
BLER	BLock Error Rate
PRB	Physical Resource Block