University of Victoria

Electrical and computer engineering

Comparison between power control algorithms in wireless communications

Name: Moneer Fakroon

Student #: V00879201

Supervision: Prof. Issa Traore

Abstract

Transmitter power control is an efficient technique to mitigate the effect of interference, near-far problem and conserve battery life. Power control algorithms in cellular radio communication systems can offer a significant improvement in the quality of service (QoS) to all users.

Choice of an appropriate power control algorithm is of prime importance, as it should aim at increasing the overall efficiency of the system. In this project four distributed power control algorithms are compared through simulations on the basis of performance metrics like signal to interference plus noise ratio and outage probability for the uplink case take into account loop delay.

Contents

List of Figures

List of Abbreviations

AOA	angle of arrival
ASDPC	Adaptive Step Distributed Power Control Algorithm
BDPC	Balanced Distributed Power Control Algorithm
BER	Bit Error Rate
BLER	Block Error Rate
BS	Base Station
CDF	Cumulative Distribution Functions
CDMA	Code Division Multiple Accesses
CPCA	Centralized Power Control Algorithm
DL	Down Link
DPCA	Distributed Power Control Algorithm
Eb/No	Energy Per Bit to Noise
ERP	Effective Radiated Power
FDPC	Fully Distributed Power Control Algorithm
FER	Frame Error Rate
Fos& Mil	Foschini and Miljanic Algorithm
FSDPC	Fixed Step Distributed Power Control Algorithm
IFDPC	Improved Fully Distributed Power Control Algorithm
MS	Mobile Station
MSC	Mobile Switching Center
PCB	Power Control Bits
PDF	Probability Density Functions
Pr	Received Power
QOS	Quality of Service
SINR	Signal to Interference Ratio
TPC	Transmission Power Control
UL	Up Link

Chapter 1

Introduction

1.1 Introduction

Transmission power control (TPC) technique is one of the most important techniques of radio resource management. It is considered crucial for wireless communication systems, especially for cellular systems. The received power by a mobile station changes noticeably because of the nature of the wireless channel and also because of the user mobility.

The importance of power control increases in non orthogonal systems such as code division multiple access (CDMA). In these systems every user interferes with other users when using high power level for transmission. This causes significant decrease in system capacity.

Mobile stations have limited power. They cannot transmit at high power level, and using low power level in transmission results in low Quality of service (QOS) and unacceptable error rate [1].

Power control is accomplished using dedicated power control algorithms. Power control algorithms work on saving the transmitted power at the minimum required power that gives the needed QOS in the communication link [1].

There are several QOS requirements that assure successful and acceptable connection. Some of these requirements are, data rate, packet delay, bit error rate (BER) and outage probability.

Signal to Interference plus noise Ratio (SINR) is usually considered as an indication for QOS. Actually, most of QOS parameters are related directly or indirectly to SINR. For example, BER and SINR are related according to the modulation type, interference and channel condition [1].

The main goal of power control is maintaining the SINR at an acceptable level, which means reducing the interference. TPC also enhances the channel capacity, decreases near-far problem, improves battery consumption, and reduces heath concerns about electromagnetic radiation.

1.2 Project Objective

The aim of this project is to evaluate the performance of some distributed power control algorithms in uplink (UL) for cellular communication system using MATLAB language. The evaluation takes into account the impact of loop delay and user mobility.

1.3 Project Outline

The project is divided into five chapters. After the introductory chapter, an overview of system model, problem formulation, power control classification and loop delay is given in chapter two. Chapter three illustrates the basics of power control algorithms both centralized and distributed. In chapter four, description of the simulation environment is given followed by the numerical results. Finally, the conclusions and high lights for future works are given in Chapter five.

Chapter 2

Power Control in Cellular Systems

2.1 System Model

Assuming a cellular communication system containing N base stations (BS) and M mobile stations (MS), one or more Mobile Switching Center (MSC), as shown in Figure 2.1.

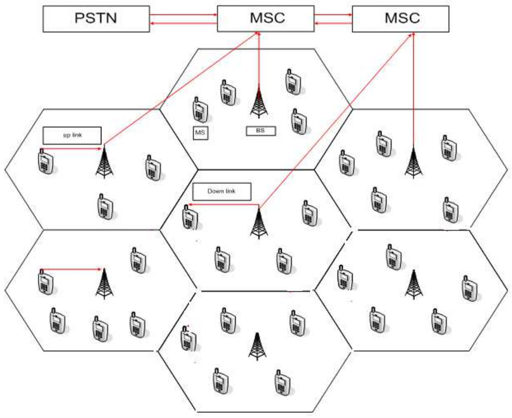

Figure 2.1: Cellular Communication System.

Each MS transmits at power level P_i. The transmitted power vector of all users can be represented as follows [2]:

$$\mathbf{P} = [P_1, P_2, P_3, ..., P_M] \tag{2.1}$$

Signal to Interference plus noise Ratio (SINR) vector can be written as [2]:

$$\mathbf{\Gamma} = [\Gamma_1, \Gamma_2, \Gamma_3, ..., \Gamma_M] \tag{2.2}$$

where Γ_i represents the SINR of the i^{th} user.
The path gain between j^{th} base station and i^{th} mobile station is (G_{ij}), $(\mathbf{G})$ represents the total gain matrix between all base stations and all mobile stations [2].

$$\mathbf{G} = \begin{bmatrix} G_{11} & G_{12} & \dots & G_{1M} \\ G_{21} & G_{22} & \dots & G_{2M} \\ \vdots & \vdots & \vdots & \vdots \\ G_{N1} & G_{N2} & \dots & G_{NM} \end{bmatrix} \tag{2.3}$$

The received SINR in the Up Link (UL) can be written as [2]:

$$\Gamma_{i \quad (up-link)} = \frac{P_i \times G_{ii}}{\sum_{\substack{j \neq i \\ j=1}}^{N} P_j \times G_{ij} + N_i} \tag{2.4}$$

where $\Gamma_{i \quad (up-link)}$ is Signal to interference plus noise ratio at base station, P_i transmission power of i^{th} mobile station, G_{ii} link gain between base station and i^{th} mobile station, G_{ij} link gain between base station and j^{th} mobile station, N_i additive noise at base station.

2.2 Problem Formulation

The presence of users in a cell covered by a single BS makes the users' signals interfere with each other at the BS. This is known as interference in UL.

In Cellular system, all users with the same level of transmission power would cause a significant difference in the received signal from each user at the BS. This difference could reach 100dB [11], therefore there will be a probability of dropping signals with low power and this is known as near-far problem.

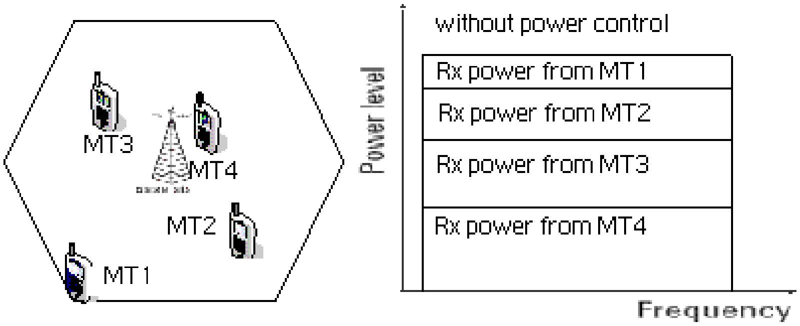

Figure 2.2: Near-Far Problem.

Figure 2.2 shows four users in a mobile cellular system. Each user is at different distance from the BS, and transmits at power P. Because of the increasing attenuation, and by neglecting the shadowing effect, the received signal power of the closer user will be higher than the other users.

Mobile phone device should be small size, so its battery should be small size too, therefore the amount of power stored in it is little and should be maintained as long as possible.

2.3 Power Control Classification

The basic purpose of Transmission Power Control (TPC) is to make the received SINR from all transmitters almost equal at the receiver. This leads to minimize the interference and increase system capacity. Power control process can be divided based on information feedback into:

1. Open Loop Power Control
2. Closed Loop Power Control

2.3.1 Open Loop Power Control

Open loop power control is the process by which to assess the status channel and adjust the transmitted power accordingly, and do not try to get feedback information about the modification efficiency. It is clear that the open loop power control is not as precise as sufficient, but it is relatively fast because it does not wait for feedback [11].

Accesses Probes

One of the problems that must be resolved by using power control is to determine the initial power level used by the mobile station in transmission process.

The MS cannot be controlled prior to the connection process with the BS. The question comes how much should be the power level used by the MS to send its request. To this moment no connection is established between the MS and BS, as well as the BS does not have any indication about the location of the user. In this case there are two options.

The first option is to make the mobile station to send with a high power level and this increases the probability of granted access, but such transmission will cause more interference to users for whom they provided service at that time.

The second option is to make the MS transmit with a low power level and this reduces the probability of granted access, but does not cause significant interference to other users.

Initial access attempts problem was solved in cellular systems by sending a series of access probes which are series of gradual increases. The MS sends an access probe with a relatively low power level in the first attempt of access and then waits a random period for acknowledgement reply from the BS. In case of no acknowledgement received, the MS sends a second access probe with a power level slightly higher and repeats this process until the acknowledgement is received. The difference in power level between the current probe and the previous probe is called access probe correction factor which determines the step size of the probe by a parameter in the system called PWR-Step [10].

If the MS found that the received signal from the BS has a high power level, it assumes that it is close to the BS, and so it sends by relatively low level of power. But if the signal received from the BS has a low power level, the MS assumes that it is far from the BS, and so it sends a relatively high power level.

By knowing the received power level from the BS, the MS can estimate the forward path loss from the base station to mobile station.

If the Effective Radiated power (ERP) of the BS is known by MS, the MS will be able to know the power amount that must be sent out to compensate the path loss. But in fact the MS does not know the actual value of ERP and does not know the power level received from neighboring stations. thus it must estimate it, and practically the following equation is used to estimate the initial transmission power [10].

$$P_{t-in} = -P_r - 73 + NOM\_PWR + INIT\_PWR \tag{2.5}$$

where (-73) is the called cellular loss constant, P_r is the received power, P_{t-in} is the initial power, the values of NOM_PWR and $INIT\_PWR$ are placed by the system operator and the BS sends the value of these two factors in addition to PWR_Step through a message called (access variables message) to MS.

It can be noted that the process is controlled by the MS. The open loop power control process goes on well after recognition of the BS request by the MS to get the connection and then the MS starts the transmission process through the communication channel. The movement of the mobile station at the cell borders, the path loss between the base station and the mobile station will change continuously, resulting in a change in the received signal level at the base station, and to maintain the quality of the connection , an adjustment must be made in the mobile station transmission power level by the following equation [10]:

$$P_t = -P_r - 73 + NOM\_PWR + INIT\_PWR + S \tag{2.6}$$

where P_t is the estimated power by the open loop that must be sent by the mobile station, S is the sum of all access probe correction factors.

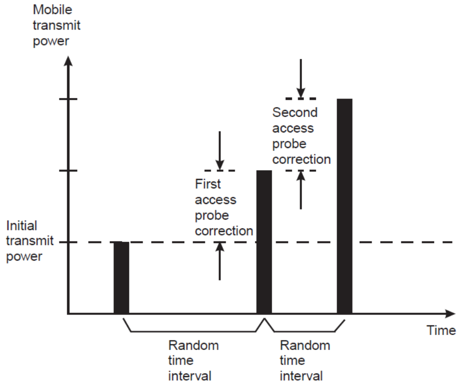

Figure 2.3: A series of Access Probes by Mobile to Access the System.

Figure 2.3 [10] shows the initial transmission power of a mobile station and its power after the addition of correction factor of the access probe.

It is important to note that the open loop power control is based on estimating the forward path loss from the base station to the mobile station, this method is used to control the power to compensate the fading and assume that the UL and DL have the same fading effect. The system uses a time division duplex (TDD) technique. But when each link uses different frequency, the frequency division duplex FDD system, the open loop power control is slow and not appropriate to compensate fading, which depends on the frequency.

2.3.2 Closed Loop Power Control

Closed loop power control system may depend on the decision-making on real measurements for the performance of communication link, such as received signal power or SINR or bit error rate or frame error rate [11].

Closed loop power control is used to compensate power changes due to fading and unlike open loop, closed loop includes both of the BS and MS in the implementation of the power control process.

In closed loop power control the BS continuously senses and measures the UL quality. If the link quality is bad, the BS will send a command to the MS via the DL to increase the transmission power level. If the link quality is good and there is a surplus in power of the UL, then, the BS will send a command to the MS to reduce the transmission power level.

The frame error rate (FER) is considered as a good indicator to measure the link quality. But because of the long time needed by the BS to collect sufficient number of bits to calculate the FER. The energy per bit to noise ratio (Eb/No) is used as an indicator to measure the link quality.
The steps of power control process of the closed loop in the uplink are as follows:

- The BS continuously senses (Eb/No) in the UL.
- If (Eb/No) is very high, in other words it exceeds a certain threshold, then the BS will order the MS to reduce the transmitted power.
- If (Eb/No) is very low, in other words it is less than a certain threshold, then the BS will order the MS to increase the transmitted power.

The BS sends power control commands to MS through the DL, and these commands, which consist of a set of bits known as power control bits (PCB), must be transmitted quickly and the MS must respond to these commands quickly to try to overcome fading. In order to make fast transmission of power control bits, a number of bits are reserved in the channel.

Closed loop power control is divided into inner loop and outer loop. What has been described so far is the inner loop of the closed loop power control. In the inner loop there is a threshold for the signal to noise ratio ($SINR_{th}$) which is predetermined; the decision-making, either by increase or decrease the power is based on this threshold.

Since frame error rate is tried to be maintained acceptably, and given the (Eb/No) relation to the frame error rate, then (Eb/No) would be changed dynamically to keep the desired frame error rate, this modification in (Eb/No) used in the loop of the closed loop power control in the outer loop of the closed loop power control.

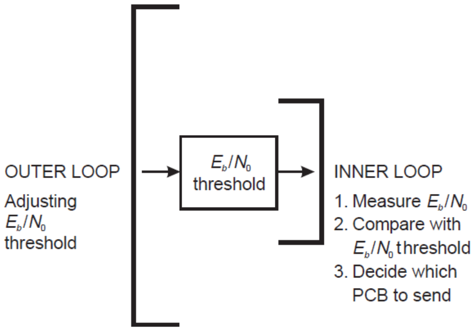

Figure 2.4: Inner and Outer Loops of the Closed Loop Power Control.

Figure 2.4 [10] shows the work done by each of the outer loop and inner loop, where in the outer loop the (Eb/No) threshold is modified and used by the inner loop to compare with the measured (Eb/No) from the uplink. Based on these comparisons, a decision would be made by the inner loop about the power control command to be sent.

Power control can be divided into centralized and distributed according to power control a location.

- **Centralized Power Control**:
  This method uses a central control device that has information about the gain of all the links in the system and uses this data to find the optimal solution for controlling the power of these links simultaneously. But this kind of process is not practical because of the complexity of the equipment and the bandwidth consumption due to the large signaling process between stations [2].

- **Distributed Power Control**:
  This process is based on gain measuring in the local link (for each user),where each base station measures parameters in their perimeter, such as link gain and SINR and control the power of its links. This kind of power control can be applied practically as it is not complicated in the signaling process and easier to implement [2].

2.4 Loop Delay

Most of the power control algorithms that have been proposed do not consider the impact of loop delay and thus lead to system instability and low capacity [3].

The main obstacle in the implementation of power control algorithms is the behavior of the channel that must be pre-estimated first. Most of the power control algorithms assume that the channel attenuation and interference is constant during the time of executing the power control process, meaning that in the calculation time of update power and the time of applying that power the channel attenuation and interference does not change.

Loop delay refers to all time delays during the execution of power control process. This delay is due to the process of SINR measurement and transmitting SINR data via radio channel. The operations applied on the SINR information to calculate and adjust the transmitted power , propagation time needed by the new power transmission to produce the SINR.

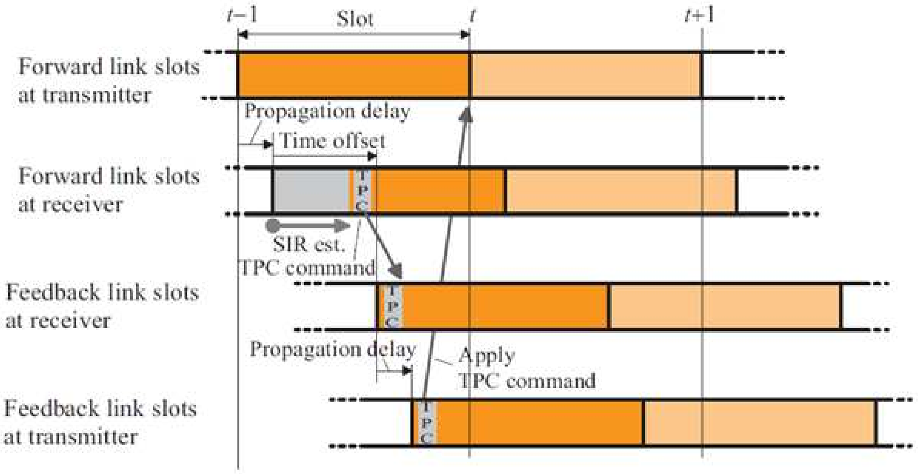

Figure 2.5: Example of Power Control Timing in WCDMA.

Figure 2.5 illustrates the power control timing. The transmitter sends a frame at t-1 which will be received after propagation time. The receiver needs an offset time to estimate the SINR and calculate the power control

command from the algorithm. The receiver sends a power control command which takes propagation time to reach the sender.
The transmitter modifies the transmission power that will be used in the next time slot according to the control command. If the delay time due to SINR estimation process and operations of calculating and sending the control command is long, it leads to sending the power at time t+1 instead of sending it at time t, and this is because of the loop delay.

- **Power Control in Soft Handover**:
  CDMA systems use the concept of flexible delivery when a MS moves between two cells or more. The concept of flexible delivery is to keep the MS to communicate with two or more BS during the handover period. In this period the MS receives messaging channel frames from two or more stations and the power control commands of these stations may conflict. The MS might receive a command from a BS to increase the power in the time that other BS sends a command to decrease the power. In this case MS will carry out the reduction command and will not increase power level, except in the case where all commands ask for power increase.

Chapter 3

Power control algorithms

Power control algorithm is the mechanism that is executed in order to set the transmit power of BS in Down link (DL) or the transmit power of MS in UL. Several power control algorithms were proposed [2][5][6]. Power control algorithms can be divided into two main categories:
- Centralized Power Control Algorithm (CPCA).
- Distributed Power Control Algorithms (DPCA).

3.1 Centralized Power Control Algorithm (CPCA)

In this algorithm, power control is executed using central control device. The algorithm needs information about the links gain and the noise levels for all users to determine the power and balance SINR. This algorithm solves the mathematical problem to find the optimal transmit power vector.

Consider the case of noiseless system, recall the SINR of i^{th} user given by (2.4). Under noiseless assumption (2.4) can be written as:

$$\Gamma_i = \frac{P_i G_{ii}}{\sum_{\substack{j \neq i \\ j=1}} P_j G_{ij}} \geq \Gamma_{i,min} \tag{3.1}$$

where $\Gamma_{i,min}$ is minimum predefined SIR for terminal i. Equation (3.1) can be written in this form:

$$P_i G_{ii} \geq \Gamma_{min} \sum_{\substack{j \neq i \\ i=1}} P_j G_{ij} \tag{3.2}$$

Equation (3.2) can be written in this form:

$$P_i \geq \Gamma_{min} \sum_{\substack{j \neq i \\ i=1}} P_j \frac{G_{ij}}{G_{ii}} \tag{3.3}$$

writing (3.3) in matrix form as follows [1]:

$$\mathbf{P} \geq \Gamma_{min} \mathbf{HP} \tag{3.4}$$

where matrix **H** is a positive matrix (each element is positive) contains the following elements [1]:

$$(\mathbf{H})_{ij} = \begin{cases} 0 & i = j \\ \frac{G_{ij}}{Gii} & i \neq j \end{cases} \tag{3.5}$$

From (3.4) and by considering the worst case:

$$\mathbf{P} = \Gamma_{min} \mathbf{HP} \tag{3.6}$$

$$\mathbf{P} - \Gamma_{min} \mathbf{HP} = 0 \tag{3.7}$$

$$[\mathbf{I} - \Gamma_{min} \mathbf{H}] \mathbf{P} = 0 \tag{3.8}$$

By multiplying both sides of (3.8) by $\frac{1}{\mathbf{\Gamma}_{min}}$:

$$[\frac{1}{\Gamma_{min}} \mathbf{I} - \mathbf{H}] \mathbf{P} = 0 \tag{3.9}$$

The solution of (3.9) represents the optimum transmit power vector. The direct solution of this equation is to set vector **P** to zero, that means every user transmits at power value equal to zero. In other meaning all mobile stations in the system must be shut down. Definitely no one would be satisfied with this solution. By matrices calculus (3.9) has a solution only if the matrix $[\mathbf{I} - \Gamma_{min} \mathbf{H}]$ is a singular matrix and that can be accomplished if and only if $\frac{1}{\Gamma_{min}}$ is the eigenvalue of **H**.

The optimum transmit power vector relates to the eigenvector according to Perron-Frobenius, so, if the normalized gain matrix (**H**) with dimension $(M * M)$ where it cannot be reduced and it's not negative, then there is a positive vector associated with the biggest eigenvalue which is also a real and positive $[\lambda]_{i=1}^{M}$ [1].

There is one eigenvalue that is positive and greater than or equal to all other eigenvalue in the sense [2]:

$$\lambda^* = \max[|\lambda_i|]_{i=1}^{M} \tag{3.10}$$

There is a positive eigenvector $\mathbf{P}^*$corresponding to the largest eigenvalue λ^*. Using the largest eigenvalue the maximum achievable SIR can be obtained as [2]:

$$\Gamma^* = \frac{1}{\lambda^*} \tag{3.11}$$

Now consider the case when the system including additive noise at the receiver equation (2.1) becomes as follows [1]:

$$P_i G_{ii} \geq \Gamma_{min} \sum_{\substack{j \neq i \\ j=1}} P_j G_{ij} + N_i \tag{3.12}$$

Equation (3.12) can be written as follows:

$$P_i \geq \Gamma_{min} (\sum_{\substack{j \neq i \\ j=1}} P_j \frac{G_{ij}}{G_{ii}} + \frac{N_i}{G_{ii}}) \tag{3.13}$$

Writing (3.13) in matrices form as follows:

$$\mathbf{P} = \mathbf{\Gamma}_{min} \mathbf{H} \mathbf{P} + \mathbf{u} \tag{3.14}$$

where $\mathbf{u} = \frac{\mathbf{\Gamma}^T \mathbf{N}_i}{\mathbf{G}_{ii}}$
(3.14) becomes as follows [1]:

$$[\mathbf{I} - \mathbf{\Gamma}_{min} \mathbf{H}] \mathbf{P} = \mathbf{u} \tag{3.15}$$

The solution of (3.15) represents the optimum power vector, which can be achieved in the case of $\Gamma^T < \frac{1}{\lambda^*}$, where Γ^T is target SINR [1]:

$$\mathbf{P}^* = [\mathbf{I} - \mathbf{\Gamma}^T \mathbf{H}]^{-1} \mathbf{u} \tag{3.16}$$

Where $\mathbf{P}^*$is the vector that represents the optimum power vector.

3.2 Distributed Power Control Algorithms (DPCA)

Unlike the CPCA, DPCA uses local information per link regardless of the other links to update power and accomplish the desired SINR. There are several DPCA proposed to achieve multiple QOS requirements. These algorithms are repetitive and converge to the desired value after a number of iterations.

Power control algorithms need an indicator of channel quality. This indicator could be SINR, BLER or received power (Pr). BLER is the most accurate indicator that expresses the channel status [1], so, the right decision can be taken to update the transmit power value. But BLER is considered poor indicator in the systems that need fast power update. The system needs long time to take full measurement of BLER, so, there is no guarantee to channel consistency in such long time frame.

Eventually, SINR is considered the optimum choice being an indicator of the channel status, because it is simple to evaluate and needs received power to be calculated faster than BLER, and there is a direct relation between SINR and BLER [1].

Since DPCA approaches the required value after a number of iterations, the iterative method will be as follows. Rewriting (3.16) in order to find the transmitted power vector considering the case of noisy system:

$$[\mathbf{I} - \Gamma^T \mathbf{H}]\mathbf{P} = \mathbf{u} \tag{3.17}$$

By defining [1]

$$[\mathbf{I} - \Gamma^T \mathbf{H}] = \mathbf{M} - \mathbf{N} \tag{3.18}$$

where $\mathbf{M}$ and $\mathbf{N}$ are dimensioned by $Q \times Q$,$\mathbf{M}$ is non-singular matrix.
From (3.17) and (3.18):

$$[\mathbf{M} - \mathbf{N}]\mathbf{P} = \mathbf{u} \tag{3.19}$$

By solving equation (3.19) iteratively the solution will be:

$$\mathbf{P}(t+1) = \mathbf{M}^{-1}\mathbf{N}\mathbf{P}(t) + \mathbf{M}^{-1}\mathbf{u} \tag{3.20}$$

when t=0 the solution of (3.20) will be:

$$\mathbf{P}(1) = \mathbf{M}^{-1}\mathbf{N}\mathbf{P}(0) + \mathbf{M}^{-1}\mathbf{u} \tag{3.21}$$

where $\mathbf{P}(0)$ is the initial transmit power.
when t=1 the solution of (3.20) will be:

$$\mathbf{P}(2) = \mathbf{M}^{-1}\mathbf{N}\mathbf{P}(1) + \mathbf{M}^{-1}\mathbf{u} \tag{3.22}$$

By substituting (3.21) to (3.22):

$$\mathbf{P}(2) = (\mathbf{M}^{-1}\mathbf{N})^2\mathbf{P}(0) + (\mathbf{M}^{-1}\mathbf{N})\mathbf{M}^{-1}\mathbf{u} + \mathbf{M}^{-1}\mathbf{u} \tag{3.23}$$

The general form will be [1]:

$$\mathbf{P}(t) = (\mathbf{M}^{-1}\mathbf{N})^t\mathbf{P}(0) + \sum_{k=0}^{t-1}(\mathbf{M}^{-1}\mathbf{N})^k\mathbf{M}^{-1}\mathbf{u} \tag{3.24}$$

Some of the existing distributed power control algorithms are the following:
- Distributed Power Control Algorithm (DPCA) [2]
- Fully Distributed Power Control Algorithm (FDPC) [6]
- Improved Fully Distributed Power Control Algorithm (IFDPC) [10]
- Balanced Distributed Power Control Algorithm (BDPC) [2]
- Fixed Step Distributed Power Control Algorithm (FSDPC) [5]
- Adaptive Step Distributed Power Control Algorithm (ASDPC) [9]
- Foschini-Miljanic Algorithm($Fos\&Mil$) [7]

In the following these algorithms and their corresponding parameters will be briefly explained.

Distributed Power Control Algorithm

This algorithm is initially used in satellite communication systems. Later it was suggested to be used in cellular phone systems. This algorithm uses the following expression to update transmit power:

$$\mathbf{P}(t+1) = \mathbf{C}(t) \times \mathbf{H} \times \mathbf{P}(t) \qquad t > 0 \tag{3.25}$$

It can be noticed that the previous transmit power values of the mobile station $\mathbf{P}(t)$ is used to calculate the next transmit power $\mathbf{P}(t+1)$, C is normalized positive constant chosen as follows:

$$C = \frac{1}{\max(P_i(t))} \tag{3.26}$$

This algorithm converges to the desired SINR and its convergence speed depends on the constant C. The main disadvantage of this algorithm is that it needs information about transmission power of all mobile stations and the use of the maximum instant value to find the normalized constant C, so it cannot be considered a fully distributed algorithm.

Fully Distributed Power Control Algorithm (FDPC)

This algorithm was called fully distributed power control algorithm because it uses local information on the link and does not depend on comprehensive information of all mobile stations to control power. This algorithm uses the following expression to update the power:

$$P_i(t+1) = K_i(t) \times P_i(t) \tag{3.27}$$

where

$$K_i(t) = \frac{\min(\Gamma_i(t), \Gamma^T)}{\Gamma_i(t)} \tag{3.28}$$

where $\Gamma_i(t)$ is the signal to interference plus noise ratio of the i^{th} mobile station at iteration t.

The only obstacle in this algorithm is that the power reaches zero after a number of iterations. As equation (3.28) shows that the constant $K_i(t)$ depends on the minimum value of all signal to interference ratios in the current iteration, and the desired signal to interference ratio, so, after a number of iterations the constant $K_i(t)$ reaches zero.

Improved Fully Distributed Power Control Algorithm (IFDPC)

This algorithm is considered as an evolution of the previous algorithm FDPC which take the minimum value of SINR in consideration. This algorithm takes the maximum value of SINR in consideration and uses the following expression to update transmission power per user:

$$P_i(t+1) = K_i(t) \times P_i(t) \tag{3.29}$$

where

$$K_i(t) = \frac{\max(\Gamma_i^t, \Gamma^T)}{\Gamma_i^t} \tag{3.30}$$

The main problem with this algorithm is that the power reaches infinity after a number of iterations. As it can be seen from (3.30) that the constant $K_i(t)$ depends on the maximum value of all SINR in the current iteration, and the desired SINR. Consequently, after a number of iterations the constant $K_i(t)$ reaches infinity.

Balanced Distributed Power Control Algorithm (BDPC)

This algorithm was suggested by Wang for CDMA systems [2]. This algorithm makes use of both algorithms FDPC and IFDPC. The power reaches neither zero nor infinity. This algorithm makes the solution by putting two limits for power, one upper (P^u) and the other lower (P^l) to balance the power. This algorithm uses the following expression to update transmission power per user:

$$P_i(t+1) = K_i(t) \times P_i(t) \tag{3.31}$$

where

$$k_i(t) = \left\{ \begin{array}{ll} \frac{min(\Gamma_i(t), \Gamma^T)}{\Gamma_i(t)} & P_i(t) \geq P^u \\ K(t-1) & P^l < P_i(t) < P^u \\ \frac{max(\Gamma_i(t), \Gamma^T)}{\Gamma_i(t)} & P_i(t) \leq P^l \end{array} \right\}. \tag{3.32}$$

where P^u is the upper limit of the transmit power, P^l is the lower limit of the transmit power. If the power level at the iteration is higher than the upper limit then FDPC algorithm is used, but if the power level at any iteration is smaller the lower limit then IFDPC algorithm is used.

Fixed Step Distributed Power Control Algorithm (FSDPC)

This algorithm was proposed by Sung and is considered to be a simple application of feedback algorithms [5]. It has many advantages such as building protected link and bandwidth utilization. This algorithm uses quantized power levels. The new power level is different compares the current power level by a constant step and the following expression can be used to update the power:

$$P_i(t) = \left\{ \begin{array}{ll} \delta \times P_i(t) & (\Gamma_i(t) < \delta^{-1}\Gamma^T) \\ \delta^{-1} \times P_i(t) & (\Gamma_i(t) < \delta\Gamma^T) \\ P_i(t) & otherwise \end{array} \right\} \tag{3.33}$$

where δ is the update step size.
The concept of this algorithm depends on the measured SINR and compares

this value to target value. If the measured SINR is less than the target value a command is sent to increase the power level. But if the measured SINR is bigger than the target value a command is sent to decrease the power level. However, if both are equal then the power level remains the same. The bandwidth can be utilized in this algorithm if two bits are used to send the power control commands [2].
This algorithm maintains the quality of mobile station link that overshoots the required target.

Generally, all the aforementioned distributed algorithms converge to the SINR target, but if new users have been accepted in the cell, then SINR for all users decrease to very low level which causes a bad quality in all links. But this is not happening when using the FSPDC algorithm where it assumes that all new users accepts a very low power level. After using the link the user tries to reach the target SINR after a number of iterations, but if the user couldn't reach that target SINR then the connection will be lost, and this algorithm can be used to achieve several quality of service requirements. The only problem in this algorithm is that it lowers the system bandwidth significantly and that is because of its strict nature in achieving quality of service.

Adaptive Step Distributed Power Control Algorithm (ASDPC)

This algorithm is regarded as one of the closed loop power control methods. This algorithm is suggested for power control in the uplink instead of the fixed step size algorithm to achieve faster convergence to the required SINR. Its concept can be briefly explained in the following points:
- The base stations measures the current SINR in every iteration for every mobile station and compare it with the target SINR.
- If the current SINR is bigger than the target SINR then the base station sends a command to lower the power to the mobile station, otherwise it sends command to increase the power.
- First power update will be as the fixed step size algorithm. Then this step size changes dynamically, i.e., if two or more orders have been received to control the power in the same direction, e.g., two orders or more require increase in the transmit power causes to increase in the update step size.
- All mobile stations respond to the power control commands and adjust

transmission power according to it.
- Power updates can be in several steps with different sizes.

Foschini-Miljanic Algorithm

This algorithm is considered to be one of the distributed power control algorithms where all the parameters that it needs to update the power level are corresponding the local link, and it has the following expression for power update:

$$P_i(t+1) = \frac{\Gamma^T}{\Gamma_i(t)} \times P_i(t) \tag{3.34}$$

Since this expression doesn't have an upper limit for the power level, some modifications made the general expression according to the following:

$$P_i(t+1) = min\left\{ \ \tfrac{\Gamma^T}{\Gamma_i(t)} \times P_i(t), P_{i,max} \ \right\} \tag{3.35}$$

Chapter 4

Results & Discussions

4.1 Simulation Environment

In this project, a cellular system simulation has been set using one cluster of seven cells. For each cell there is one base station in its center and the users are uniformly distributed, assuming a mobility model using a normal random distribution for the velocity while maintaining the same angle to the user with the axis x . Therefore, the displacement of each user to a new position can be calculated as follows:

$$P_{new}(x,y) = P_{old}(x,y) + Delta(x,y) \tag{4.1}$$

where $P_{new}(x,y)$ is the new position of the user, $P_{old}(x,y)$ is the old position of the user, $Delta(x,y)$ is the increase amount and can be calculated as follows:

$$Delta = T_s * V \tag{4.2}$$

where T_s is the time that it takes for the user to arrive to the next location and is calculated by the following formula:

$$T_s = T_p/X \tag{4.3}$$

where T_p is the duration time for power control, assuming that the system is CDMA then $T_p = 1/3400sec$.
X is a positive integer corresponding to the amount of loop delay.

Figures (4-1) to (4-4) depict the flow charts to study power control in uplink by the algorithms that were described in the previous chapter (FSDPC, FDPC, IFDPC, Fos&Mil).

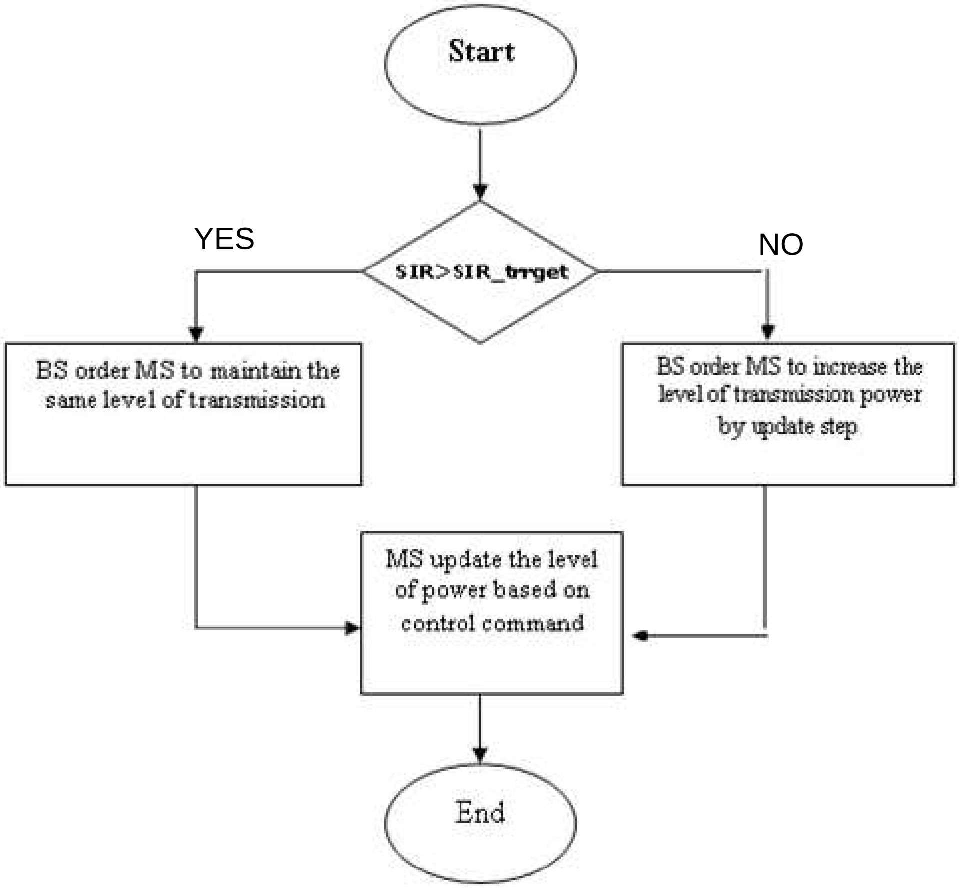

Figure 4.1: Flow Chart of FSDPC Algorithm.

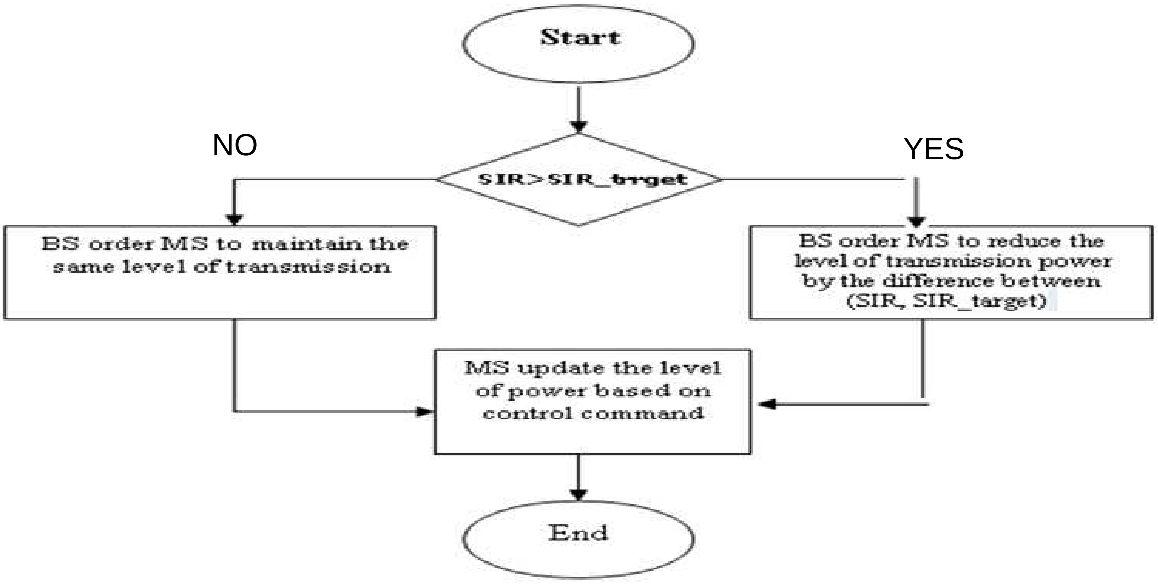

Figure 4.2: Flow Chart of FDPC Algorithm.

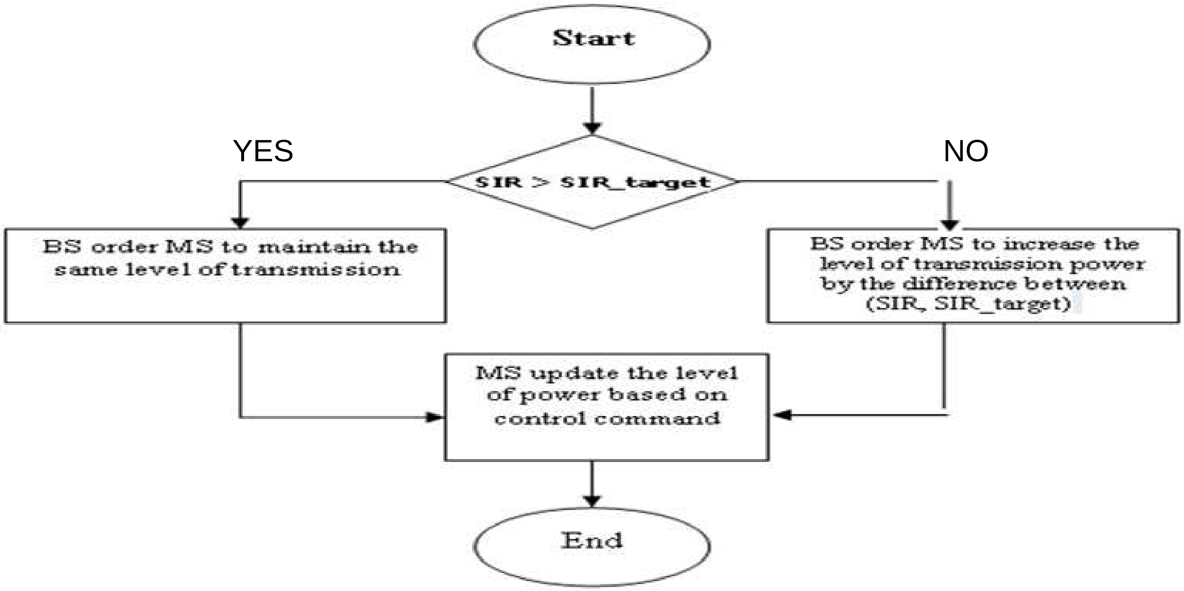

Figure 4.3: Flow Chart of IFDPC Algorithm.

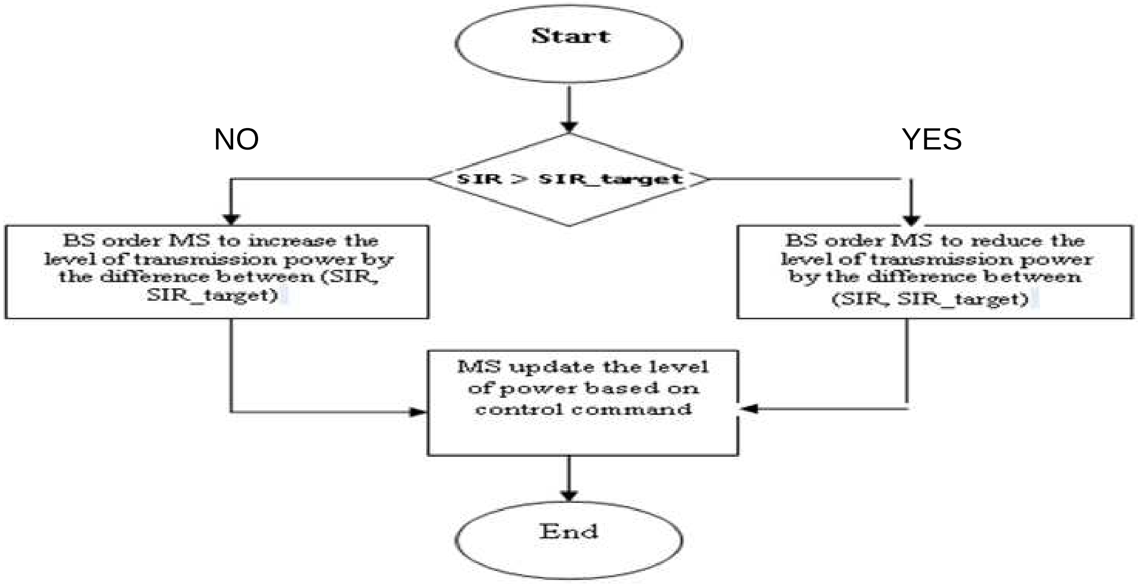

Figure 4.4: Flow Chart of Fos &Mil Algorithm

4.2 Simulation Setup

In the following results a simplified path loss is assumed with the following parameters: the operating frequency is 2GHZ, the path loss exponent is $\gamma = 3$, shadowing generated using average $\mu = 0dB$, a standard deviation $\sigma = 3dB$. With the assumption of a hundred users in each cell having the same level of transmission power initially of (1dBm), the cell is hexagonal shape with a radius of 1Km, the desired target level for all users ($SINR_{traget} = -20dBm$), with tolerance of ($\pm 2dBm$). The outage percentage allowed in the system is (5%).

- **Cluster Shape**:

Figure 4.5 shows a cluster of 7 cells under study and the distribution of users within it. Each cell is a hexagon of radius (1Km) which represents Micro Cell scenario. There are one hundred users within each cell uniformly distributed.

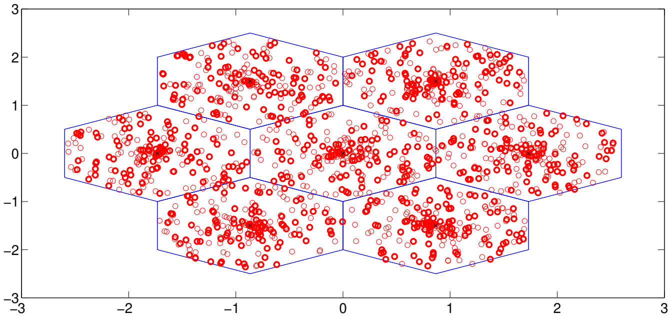

Figure 4.5: Cluster Shape.

4.3 Results and Discussions

4.3.1 Convergence Speed

The primary purpose of implementing the power control algorithms is to reach the allowed percentage of outage in the cellular system. This is done after a certain number of iterations of power level updates. The number of iterations depends on the quality of the used algorithm. This parameter is known as convergence speed of the algorithm.

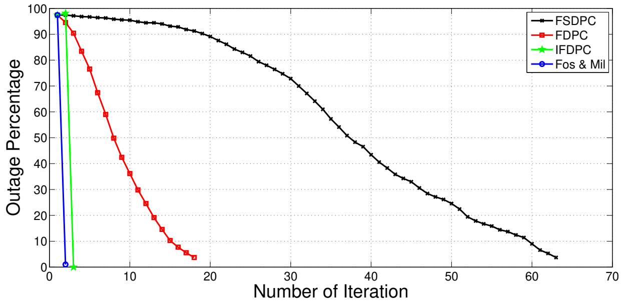

Figure 4.6: Convergence Speed of Different Power Control Algorithms.

Figure 4.6 shows the convergence speed of different power control algorithms. It can be noticed that the outage percentage was 98% before the start of the power control process. If all users use the same level of transmis-

sion power, then in each cell about 98 users will be out of service.
The outage rate decreases significantly for some algorithms. The Foc,Mil algorithm was able to reach the allowed outage percentage in the first iteration due to use of the difference magnitude between $(SINR, SINR_{target})$ as a step size for updating the power level. The IFDPC algorithm comes second as it reaches the allowed outage percentage in the second iteration.

The FSDPC algorithm has the worst performance in terms of convergence speed. It needs about 37 iterations to reduce the outage percentage to 50% and to reach the allowed outage percentage it required 63 iterations. The reason for this is because the algorithm uses fixed step size to update the power.

4.3.2 Transmission Powers after Convergence

Because of the divers mechanism of each algorithm (step size update) that causes a divers transmission power level at the algorithms convergence.

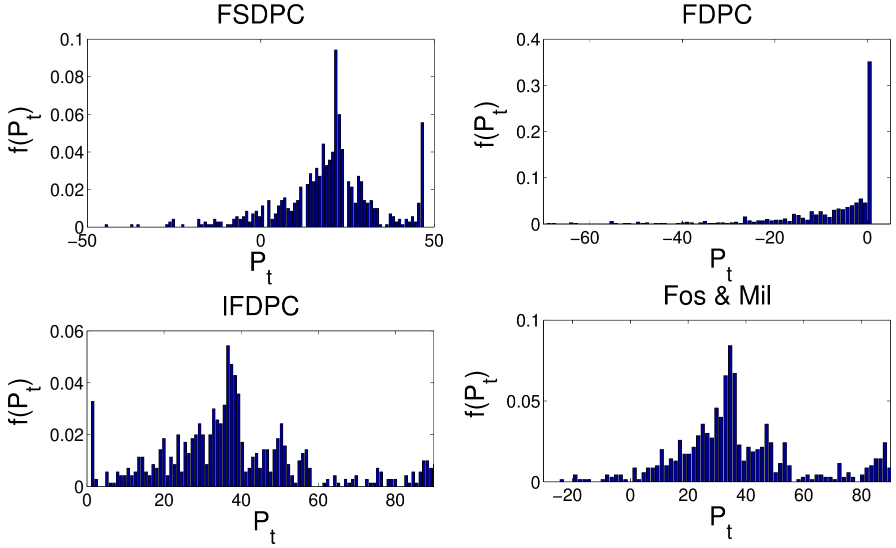

Figure 4.7: Transmitted Power for all Users after Convergence.

Figure 4.7 shows the differences between algorithms according to the power level after the convergence, where the x-axis represents transmission powers of all users after convergence and the y-axis represents the percentage of transmission powers of all users after convergence Probability Density Functions (PDF). It can be noticed that the FDPC algorithm is the best in terms of power consumption where the power level for all users is as low as -60dBm and the average power for all users is 0dBm. The IFDPC is worst in terms of power consumption where the average power level for all users is 38dBm to achieve the convergence and the power level for one user can reach 90dBm.

4.3.3 Transmission Power of Far and Near User

Power control algorithms adjust the transmission power to achieve the balance of signal to interference ratio at the base station.

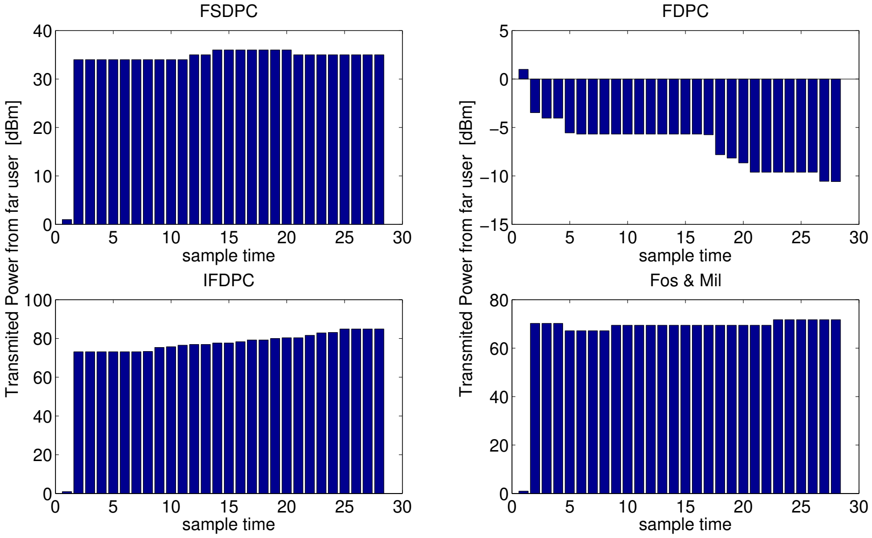

Figure 4.8: Transmitted Power from Far User with Sample Time.

Figure 4.8 shows the transmitted power of a far user during his movement period. During the movement period all algorithms increase the transmitted power for this user because of being far from the base station, but FDPC algorithm decreases the transmitted power because the concept of this algorithm is to reduce the transmission power.

Near user will suffer less loss because of the small distance to BS. All algorithms tend to decrease the transmitted power of near users.

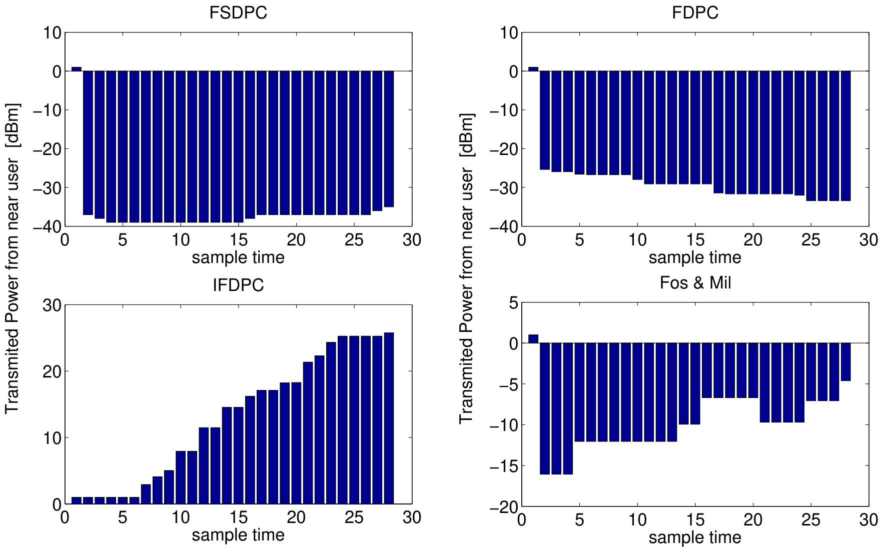

Figure 4.9: Transmitted Power from Near User with Sample Time.

Figure 4.9 shows the transmitted power of a near user during his movement period, all algorithms will reduce the transmitted power except the IFDPC algorithm where its mechanism tends to increase the transmission power of the user. Comparing it with the far user it can be noticed that the power increase value was bigger in the case of far user, where in FDPC algorithm, reduction in power was bigger in the case of the near user.

4.3.4 Signal to Interference Ratio Target Tolerance

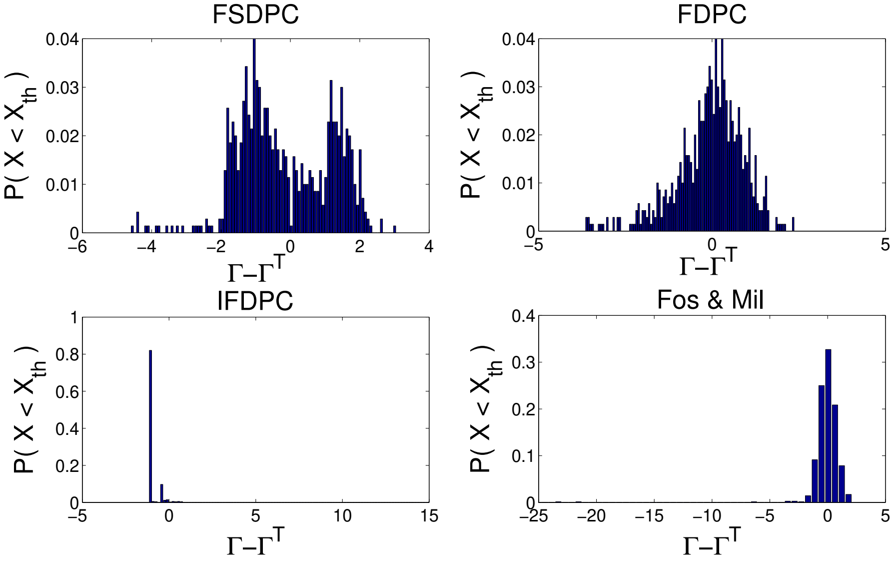

Figure 4.10: Difference Between SINR on SINR Target.

Figure 4.10 illustrates the difference between $SINR$ on $SINR_{target}$. In FSDPC algorithm almost all users have the required service level except for a few users are under the acceptable level (-2dBm) and the target tolerance for the most users ranges from (-2 to 2 dBm). FDPC algorithm it makes all users have the same required service level i.e have the same target tolerance. In IFDPC algorithm all users have the same required service level but the target tolerance for the majority of users were negative and within the acceptable range and it can be noticed that there are some users who target tolerance that reaches a 15 dBm which means that their reception power level is high and $SINR$ is low. In the case of $Fos\&Mil$ algorithm, then it has a big convergence in terms of target tolerance, and it can be noticed that some users are out of service state and while most users are in the required target level.

4.3.5 Effect of Path Loss Exponent on Performance of FSDPC Algorithm

The concept of path loss exponent that the more this factor means an increase of the obstacles that cause the multi path, which results in an increase in the loss done to the signal during its transmission from the sender to the receiver, low reception power.

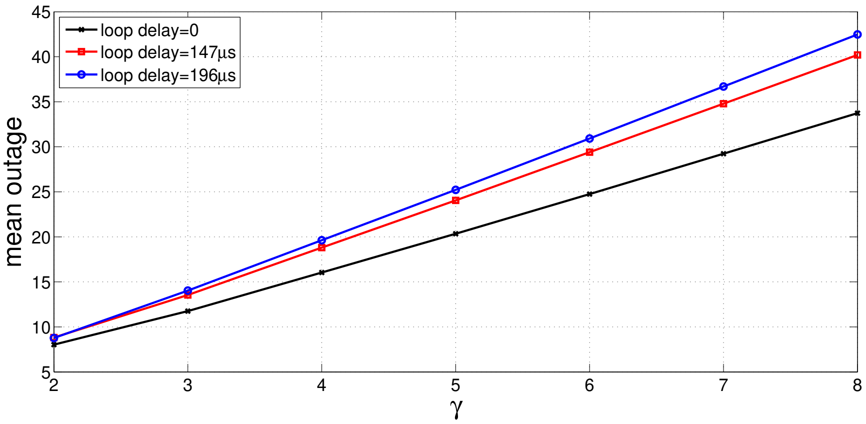

Figure 4.11: Effect of Path Loss Exponent and Loop Delay on Performance of FSDPC Algorithm.

Figure 4.11 shows the study of the performance of FSDPC algorithm in different environments (different Path Loss Exponent) considering the effect of loop delay. The average outage percentage rises considerably with γ where at $\gamma = 2$ the average outage percentage is under 10% while at $\gamma = 8$ the average outage percentage gets almost 30%, the loop delay boosts the average outage percentage even more.

4.3.6 Effect of Step Size on Performance of FSDPC Algorithm

The performance of FSDPC algorithm is affected by the update step size. In Figure 4.6, it can be noted that the FSDPC algorithm was the worst in terms of speed convergence, where the step size in this case was (1dBm).

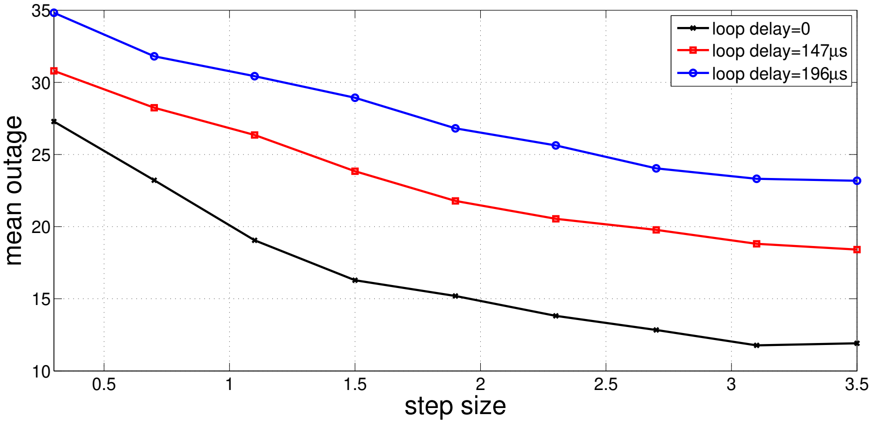

Figure 4.12: Effect of Step Size on Performance of FSDPC Algorithm.

Figure 4.12 shows the performance of FSDPC algorithm for several steps size of the power update. As it can be noted that by boosting the step size from 0 to 3.5 will decreases the average outage percentage. In contrast, the average outage percentage increases with increasing the loop delay.

4.3.7 Effect of Loop Delay on Performance of FSDPC Algorithm

Implementing the transmission power control without considering the loop delay effect, causes inaccurate results, that do not represent the actual status of the system.

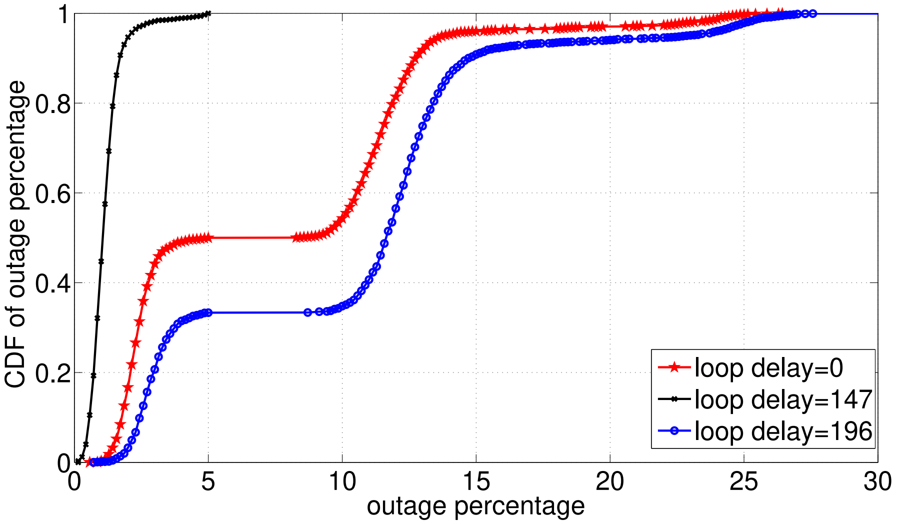

Figure 4.13: Effect of Loop Delay on Performance of FSDPC Algorithm.

Figure 4.13 shows the effect of loop delay. Where x-axis represent average outage percentage, y-axis represents probability of average outage percentage cumulative distribution functions(CDF), considering three states of loop delays at 0,147,196μsec. When loop delay=0μsec average outage percentage of the system is 100% of the time in the acceptable level,i,e, less then 5%, but when loop delay=147μsec then about 50% of the time in the acceptable level and in about 90% of the time the average outage percentage is less than 13%, when loop delay=196μsec then about 30% of the time in the acceptable level, and in 90% of the time the average outage percentage is less than 15%.

4.3.8 Effect of SINR Target on Performance of FSDPC Algorithm

The required level of service is related to the number of users within the cell where the best level of service can be achieved when the received power from all users are equal at the base station.

Since the study was for a one hundred users per cell, the best level of service that can be achieved is -20dBm according to the expression that is calculated to indicate the level of interference mentioned in Chapter 2.

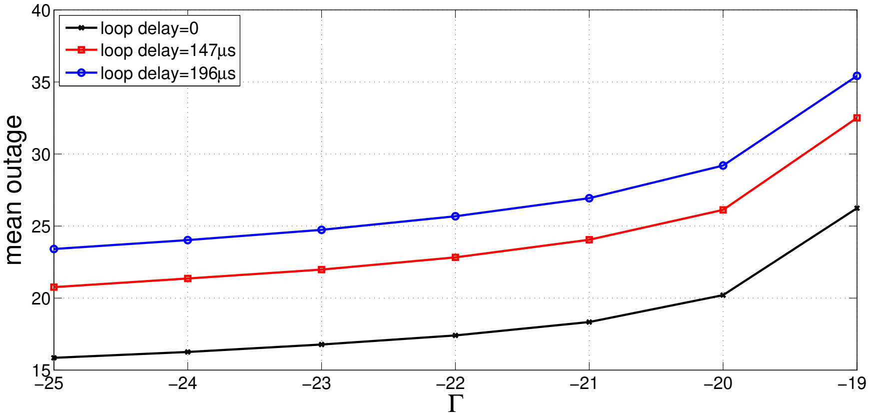

Figure 4.14: Effect of SINR Target and Loop Delay on Performance of FS-DPC Algorithm.

Figure 4.14 shows the relativity of the level of service to the average outage percentage. It can be noticed that the average outage percentage increases with increasing the level of service required (SIR_{target}). When ($SIR_{target} = -25$), the average outage percentage was 16% and the curve to rise slightly until ($SIR_{target} = -20$), the curve slope increases dramatically after (-20dBm). Note that with increasing loop delay the average outage percentage increases.

4.3.9 Effect of Shadowing on Performance of FSDPC Algorithm

Shadowing also known as slow fading, which is caused by the terrain variation, the applied reflections, refractions and scattering on the signal by the buildings, trees and rocks result in small changes in the signal average over distance.

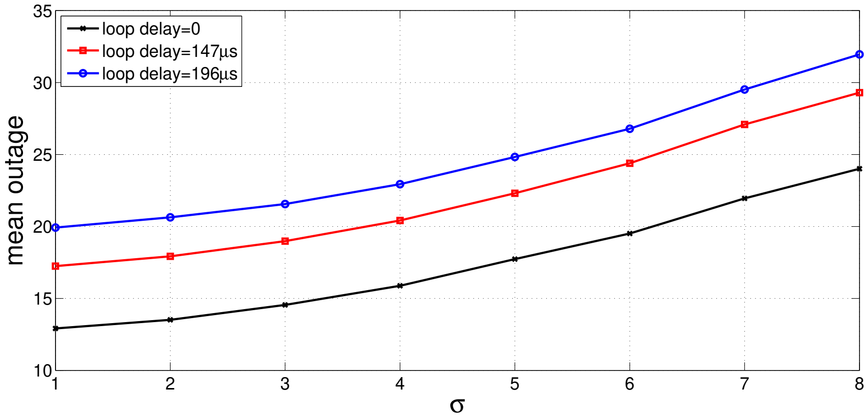

Figure 4.15: Effect of Shadowing and Loop Delay on Performance of FSDPC Algorithm.

Figure 4.15 shows that the average outage percentage showa a steady increases with the effect of Shadowing where at $\sigma = 1dB$ the average outage percentage is under 14% while at $\sigma = 7dB$ the average outage percentage gets almost 24%, the loop delay boosts the average outage percentage even more.

Chapter 5

Conclusions and Future Work

5.1 Conclusions

In this project the concept of power control in cellular systems is extensively studied. The performance of different basic distributed power control algorithms is evaluated and compared on the basis of the simulations in MATLAB. The following conclusions were reached:

- All algorithms are able to reach the allowed outage rate.
- Whenever the desired goal level less, the algorithms will be able to reach the target faster.

Features	FSDPC	FDPC	IFDPC	$Fos\&Mil$
Convergence Speed	64 Iterations	18 Iterations	2 Iterations	1 Iterations
Average Power Consumption	18 dBm	0 dBm	38 dBm	34 dBm

- In terms of convergence speed, the best algorithm is the $Fos\&Mil$ and the FSDPC algorithm is the worst.
- In terms of power consumption, the best algorithm is the FDPC and the IFDPC algorithm is the worst.

5.2 Future Work

This work represents the first step to study the issue of power control in cellular systems and needs to be supplemented. So will do the following:

- Evaluate the performance of algorithms in down link.
- Building cellular system consists of a greater number of cells.
- Add borders to the transmission power levels of each user (the maximum and minimum).

Bibliography

[1] M. Elmusrati, and H. Koivo, "Systems Engineering in Wireless Communications", *John Wiley δ Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, United Kingdom*, 1^{st} Ed, 341 pages, 2009.

[2] V.K. Vemasani,and B.S. Appuni, "Master's Thesis on Performance Evaluation of Power Control Algorithms in Cellular Radio Communication Systems,"*School of Engineering Blekinge Institute of Technology Karlskrona, Ronneby Sweden*, 40 pages, 2005.

[3] M. Rintamki, "Adaptive Power Control in CDMA Cellular Communication Systems ," *Helsinki University of Technology Signal Processing Laboratory, Finland*, 169 pages, 2005.

[4] F. Gunnarsson, "Power Control in Cellular Radio Systems: Analysis, Design and Estimation", *Department of Electrical Engineering, Linkopings universitet, Sweden*, 245 pages, 2000.

[5] C.W. Sung, and W.S. Wong,"A Distributed Fixed-Step Power Control Algorithm with Quantization and Active Link Quality Protection", *IEEE Transactions on vehicular Technology*, VOL. 48, NO. 2, pp. 553−562 March 1999.

[6] T.H. Lee, and J.C. Lin,"A Fully Distributed Power Control Algorithm for Cellular Mobile Systems," *IEEE Jourual on Selected Areas in Communication*, vol. 14, no. 4, pp. 692−697, May. 1996.

[7] M. Xiao, N.B. Shroff, and E.K.P. Chong,"Resource Management in Power Control Cellular Wireless System,"*School of Electrical and Computer Engineering Purdue University West Lafayette IN 47907-1285 U.S.A*, vol. 50, no. 5, pp. 808−821, May2002.

[8] R. Esmailzaden, M.Nakagawa,"TDD-CDMA for Wireless Communication", *IEEE J. on Selected Areas in Commun.*,PP.176,2003.

[9] S. Das, S. Ganu, N. Rivera, R.Roy"Performance Analysis of Downlink Power Control in CDMA Systems," ,pp.23, April30,2003 1978.

[10] S.C. Yang,"CDMA RF System Engineering," *Boston, london*, vol. 66, no. 9 , pp. 280,1998. 1978.

[11] R. Pichna , Q. Wang,mobile xommunications Handbook"Power control," *CRC Press LLC*, pp. 14,1999. 1978.

[12] T.S Rappaport,"Wireless Communication," *Indian*, 1st Ed, pp. 707,2002. 1978.