Power Control in DS-CDMA Forward Linkin Mobile Channels

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Submitted to the
Institute of Graduate Studies and Research
In Partial Fulfilment of the Requirements for the Degree of

Master of Science
in
Electrical and Electronic Engineering

Eastern Mediterranean University
June 2011
Gazimağusa, North Cyprus

Approval of the Institute of Graduate Studies and Research

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ABSTRACT

In this thesis, performance of Direct Sequence Code Division Multiple Access(DS-CDMA) in wireless cellular communication system is investigated using Closed Loop Power Control (CLPC).Power control is significant in a DS-CDMA system, which is to reduce Multiple Access Interference (MAI) and near-far problems. In CDMA, the entire mobile users share the same frequency band simultaneously. Hence, they all interfere with one another. The significance of CLPC is to maintain the received signal strength at the desired level. The desired values are set by Base Station(BS) in order to keep the Bit-Error-Rate(BER)at anacceptable level with minimum possible transmission power.System performance is demonstrated with BER comparisons. It is shown that CLPC optimizes transmission powersand improves the capacity of the system. The proposed power control scheme is based on estimated signal strengths. The performance of CLPC algorithm and the DS-CDMA system is examined in AWGN and fading channels. The simulations are implemented on MATLABsoftware environment.

Keywords: Wireless cellular communication systems, DS-CDMA, Closed Loop Power Control

ÖZ

Bu tezde, kablosuz hücresel haberleşme sistemi olan Doğrudan Dizili Kod Bölmeli Çoklu Erişim (DD-KBÇE) başarımı Kapalı Çevrim Güç Denetimi (KÇGD) kullanılarak incelenmiştir. Güç denetimi Çoklu Eerişim Girişimi (ÇEG) ve Yakın-Uzak sorunlarını azaltmak için DD-KBÇE sistemlerinde DD-KBÇE kullanılmaktadır. DD-KBÇE sistemlerinde tüm mobil kullanıcılar aynı frekans bandını paylaşmaktadırlar. KÇGD denetiminin amacı alınan sinyal gücü dengesini sağlamaktır. İstenen sinyal gücü değerleri Yer İstasyonu (Yİ) tarafından en az Bit Hata Oranı (BHO) göz önüne alınarak belirlenmektedir. Sistem başarımı BHO karşılaştırmaları kullanılarak incelenmiştir.KÇGD iletim güçlerini denetleyerek sistemin kapasitesini artırmaktadır. Önerilen güç denetim sistemi kestirilen sinyal güçlerine göre belirlenmektedir. KÇGD algoritması ve DD-KBÇE sisteminin başarımı AWGN ve sönümlemeli kanallarda incelenmiştir. Benzetimler MATLAB yazılımı kullanılarak gerçekleştirilmektedir.

Anahtar Kelimeler: Kablosuz hücresel haberleşme sistemleri, DD-KBÇE, Kapalı Devre Güç Denetimi.

To my parents

Nahid Abdollah pour Vafaie and Latif Aghajamaliaval

ACKNOWLEDGMENTS

I would like to thank Assoc. Prof. Dr. Aykut Hocanın for his continuous support and guidance in the preparation of this thesis. Without his invaluable supervision, all my efforts could have been short-sighted.

I owe extremely to my family who supported me throughout my studies. I would like to dedicate this study to them as an indication of their significance in this study as well as in my life.

I also would like to express my sincere appreciation to the jury committee members, Prof. Dr. Şener Uysal, Assoc. Prof. Dr. Hasan Demirel, who accepted to share their time in reviewing my research and then directing me at the thesis defense meeting.

I also wish to thank all the faculty members at the department of Electrical and Electronic Engineering, and specially the chairman, Assoc. Prof. Dr. Aykut Hocanın, who has given me the great opportunity of research assistantship.

In addition, I wish to sincerely thank all my friends who kindly shared their knowledge and experiences with me.

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A_b	Bit Amplitude
c	Speed of Light
C	Spreading Code
D	Despreading Value
E_b	Bit Energy
F_b	Amplitude Factor
F_c	Centre Frequency
F_m	Doppler Shift
G	Processing Gain
I_e	Estimation Interval
K	Number of User
N	Period
N_c	Code Length
N_0	Noise Energy
P_d	Desired Power
P_t	Transmitted Power
P_r	Received Power
P_{r_ave}	Average Received P
P_x	Power Spectral Density
R_{xx}	Aouto-Correlation Function
S_w	Window Size
T	Code Period

T_b	Time Period
T_c	Chip Period
v	Speed of Mobile
Δ_{ws}	Step Size
τ	Time Shift
1G	First Generation
2G	Second Generation
3G	Third Generation
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
CDMA	Code Division Multiple Access
CLPC	Closed Loop Power Control
DS	Direct Sequence
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
ICI	Inter Chip Interference
i.i.d	Independent Identically Distributed
ISI	Inter Symbol Interference
LOS	Line Of Sight
MAI	Multiple Access Interference
MLE	Maximum Likelihood Estimation
OFDM	Orthogonal Frequency Division Modulation
PCC	Power Control Command
PCE	Power Control Error

pdf	Probability Distribution Function
PN	Pseudo Noise
PSD	Power Spectral Density
PSK	Phase Shift Keying
QPSK	Quadrature Phase Shift Keying
RF	Radio Frequency
SINR	Signal to Interference plus Noise Ratio
SIR	Signal to Interference Ratio
SNR	Signal to Noise Ratio
SNV	Signal to Noise Variance
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
WCDMA	Wideband CDMA
WSS	Wide Sense Stationary

Chapter 1

INTRODUCTION

The widespread use of cellular communication systems have been increasing in the past two decades. The first generation (1G) systems were analogue and only voice services were provided by the system. The main enhancement of 1G, was digital communication technology. Higher Quality of Service (QoS), increased capacity and error correction coding, were available in second generation (2G) systems. Global System for Mobile Communications (GSM) was proposedin 2G systems. To further improvements, novel foundations useful for the fast wireless data transmission are being studied throughout the world. These new developments were introduced in third-generation (3G) systems. Many new functions such as file transfer, web browsing and streaming video are applied in new wireless generations. In Europe, the 3G system is named the Universal Mobile Telecommunication System (UMTS) [1], [2].Multiuser wireless communication systems are technologies that have been developed recently. Due to the increasing demands for mobile services, channel capacity is going to be even more limited. Therefore, multiple access methods will be required to remedy this problem.

The two traditional types of multiple access techniques that have been applicable are Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA) methods. These methods both apply orthogonally. TDMA method applies orthogonally in the time domain. Each user is assigned an allocated time interval. However, all users can use the entire bandwidth for communication issue in the specific time. FDMA method is used orthogonally in the frequency domain, by assigning a frequency slot to every user. Hence, the allocated bandwidth is subdivided among the users. The methods mentioned above have some limitations regarding capacity, performance and complexity. In fact, TDMA method has an unacceptable restriction when users may sometimes have to wait in order to get the chance to communicate. Consequently, each user may suffer some time loss due to waiting. Similarly, the above situation is inherent in FDMA method and accessible bandwidths are partitioned among the users into specific channels. The number of channels is limited and when a channel is occupied, other users cannot access the channel. Moreover, while each channel is occupied just once for each user, the total capacity of the system will be severely limited. To modify this problem, FDMA method employs frequency re-use method. The same specific set of frequencies can be re-used for cells where they are sufficiently placed far from each other. When signals from one cell reach the other cell with the same specific frequency, the received signals will be without much interference. Regular cell networks operate a 7-way frequency re-use pattern illustrated in figure 1, where every colour symbolizes a specific frequency. In figure 2 the mentioned multiple access methods are compared together.

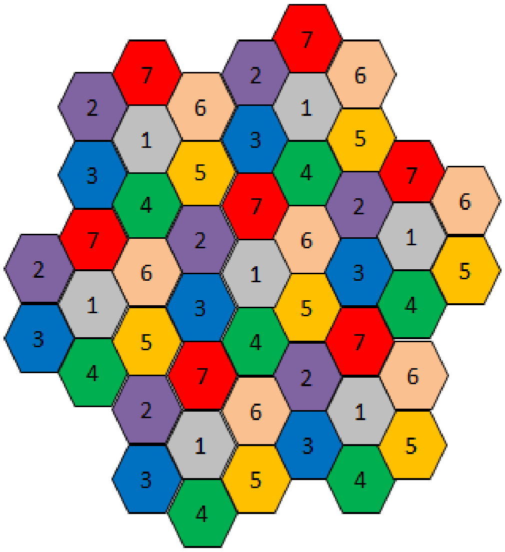

Figure 1. Frequency re-use for FDMA (7-cell model)[3]

There are some advantages in Code Division Multiple Access (CDMA) method compared with the previous methods (FDMA and TDMA). Figure 3 illustrates the frequency re-use in CDMA. This method does not require time or frequency division for multiple access. However, CDMA method needs careful planning without which an acceptable multiple access is impossible. One of the significant considerations in CDMA system is controlling the transmitted powers of users.

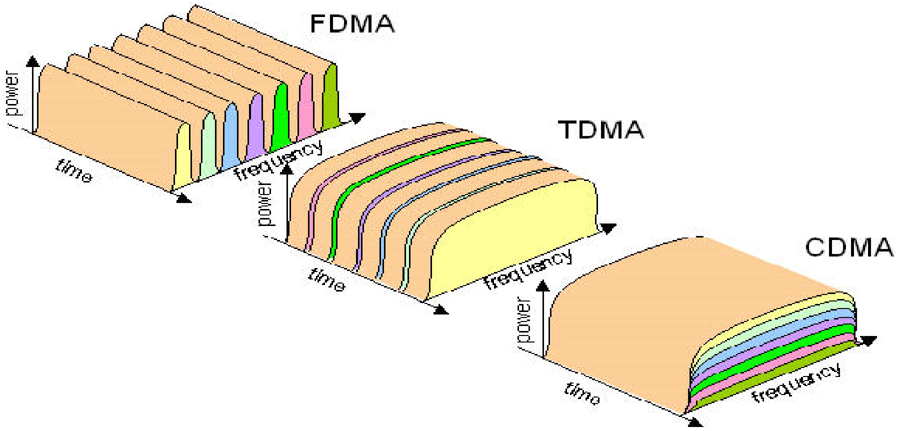

Figure 2.Comparing different multiple access methods

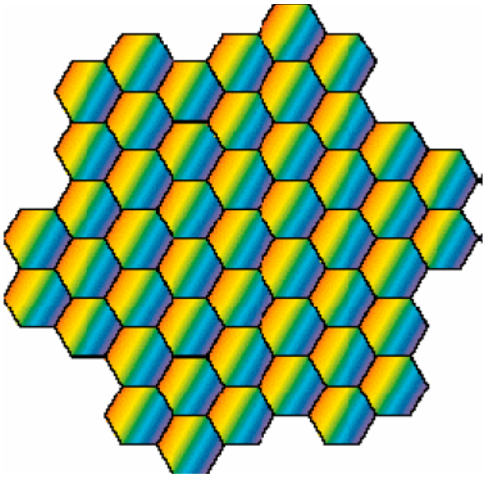

Figure 3.Frequency reuse for CDMA[3]

In this thesis, our aim is to investigate the important problem of power control in CDMA systems. Power control in CDMA systems, is a major function for controlling the effect of multiple access interference (MAI). A closed loop power control method is proposed which is fast and reduces power imbalance amongst users. The organization of this work is as follows:

In this starting chapter, the outline of the thesis is described. In Chapter 2, CDMA systems, Spreading Codes and the mobile wireless channel are briefly described. In the first part of Chapter 3, various methods of power control in CDMA are introduced, in the second part, the proposed power control method is detailed. Chapter 4 contains simulation results obtained using the MATLAB software. Chapter 5 relates to the conclusions and extensions to further work.

Chapter 2

DIRECT SEQUENCE CDMA SYSTEMS

2.1 Direct Sequence

Code Division Multiple Access (CDMA) as mentioned earlier comprises two distinct types:1. Direct Sequence (DS) type and 2. Frequency Hopping (FH) type. In this thesis, direct sequence is applied since it is very widely used due to its compatibility and capacity. The DS-CDMA method provides a multitude of benefits in cellular systems including ease in designing frequency channels and protection against interference, provided that a high processing gain is used [4].

In Direct Sequence CDMA (DS-CDMA) systems, each user's original signal (data)is multiplied by its own unique specific code. User's code is orthogonal to the others. In contrast to the traditional multiple accesses that divide the time or frequency into different slots, DS-CDMA method intersects every transmission on the same bandwidth. Therefore, all users use the full bandwidth simultaneously. The codes are binary ones that are generated by a code generator [5]. The code generator usually uses sequential logic circuits (e.g. feedback shift register). Each bit of the code is named a chip that is familiarized by the transmitter and receiver. The chip rate signifies the rate at which spreading signals are transmitted.

At the receiver end, spread signals are decoded via correlation functions (Cross and Auto correlation). Cross correlation with the particular codes despreads the received signals(spread signals)and retrieves the transmitted signal similar to the user's original signal. The spreading sequences can be mutually orthogonal with zero cross correlation, or random sequences with low cross-correlation properties. Cross correlating the desired user's signal from an undesired user's signal leads to a high value, thus the receiver treats this signal the same as correlation noise, therefore eliminates it [5].

The DS-CDMA transmission bandwidth is in a way wider than the required signal bandwidth. This is achieved by encrypting the user signal with a unique code sequence of and thus has a much wider bandwidth compared to the original user signal. Many despread signals can intersect the same bandwidth without critically interfering with each other.

One of the many advantages of using DS-CDMA is for instance: it has an interference rejection property as such; every user is identified with a specific code sequence which is almost orthogonal to the other users' codes.

The DS-CDMA also excludes the need of channel dividing thus all users use the entire channel bandwidth. Moreover, it is highly rigid to multipath fading. Signals in DS-CDMA systems are identical strength entire a wide bandwidth which can manipulate the multipath fading to modify the system's output. This is accomplished by using a simple RAKE receiver that applies a bank of compatible codes. Every correlator will relate to a specific multipath fading of the received data. According to the strengths, the correlated signals are weighted and merged to obtain the optimum signal estimate [6]. There is a good overview of CDMA in [7], with an additional described historical review of the development of the field. An instance of mono user DS-CDMA system is seen in Figure 4.

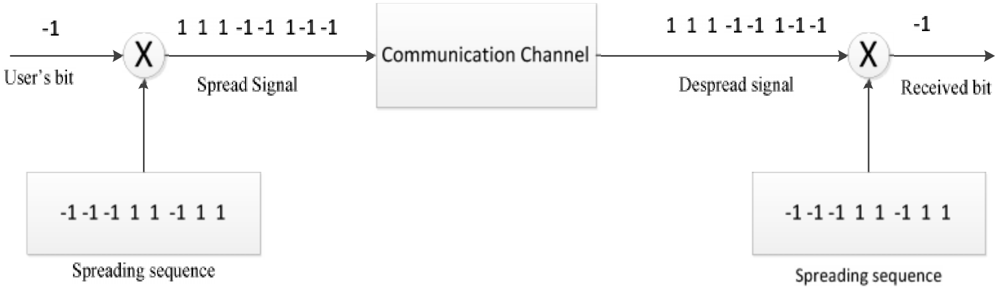

Figure 4. A user signal in DS-CDMA system

In Figure 4, an analysis of the system for one user is given and also the communication channel expected to be the ideal channel [5].Figure 5 illustrates the fundamental processes of spreading and despreading for a DS-CDMA System.

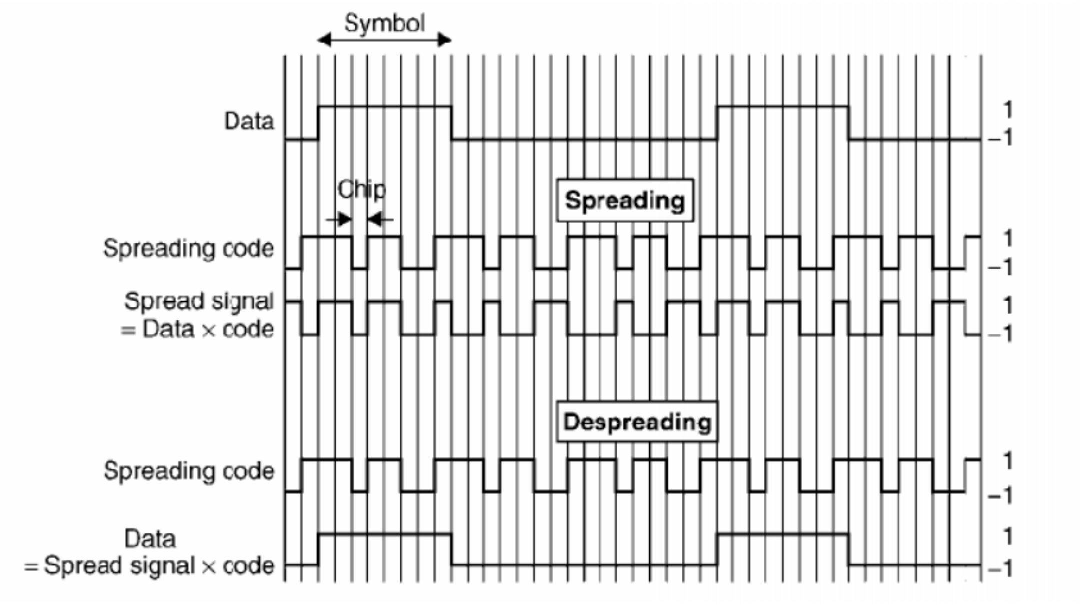

Figure 5. Transmission signal in DS-CDMA [5]

The BPSK modulator is used to convey user data. In this example, the spreading operation is the encoding of each user's original signal bit multiply by 8 chips. This spread signal is then sent through a wireless communication channel. Despreading the spread signal at the detector, is done by taking the product of each bit of a spreading signal by a compatible 8 chips used in the spread data bits. Figure 5 shows that the original user bit sequence has been restored.

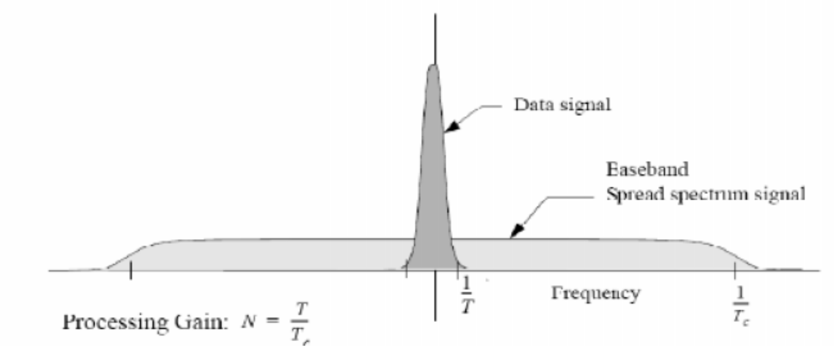

Figure 6. Original signal and spread signal [5]

Figure 6 shows the power spectral density (PSD) of a baseband spread spectrum signal. In order to maximise the entire accessible bandwidth, an original signal(narrowband) is encoded to a despread signal (wideband). Figure 7 shows PSD of spread signal and its interference.

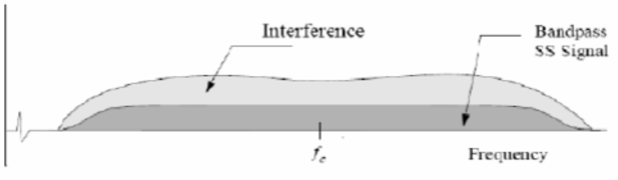

Figure 7. Spread signal and interference [5]

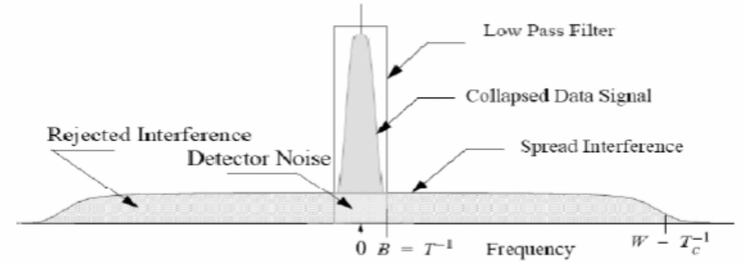

Figure 8. Despreading the spread signal and Interference of noise [5]

The PSD of a wideband spread signal in baseband and interference of noise after despreading is depicted in Figure 8. It demonstrates how the noise part may intersect with the detected signal causing interference of noise to drop inside the frequency domain of the detected signal. Therefore, this method supports the spread signal against interference. However, DS-CDMA undergoes some implementation problems in wireless communication systems. These include;

1. *Multiple access interference (MAI):*MAI restricts performance and the capacity of DS-CDMA systems. Itresults from the random time offsets among users' signals that leads to be it very difficult to create perfectly orthogonal codes. The MAI caused by any specific user is normally minimal. When the number of total users increases in the system, so does the performance of the DS-CDMA system declines drastically, since the capacity of a DS-CDMA system is limited by MAI. Multiple access interference must therefore be considered in any performance analysis of DS-CDMA system carried out. These are; MAI on the Signal-to-Noise-Ratio (SIR) and Signal-to-Interference-Ratio (SIR) and the related bit error rate (BER) at the receiver on the data sequence has to be taken into account.
2. *Complexity:* To obtain the optimum entire multipath variety, there is need to use a suitable detector like matched filter receiver approached via a simple RAKE receiver. The RAKE receiver should be designed with the suitable number of

paths. The time variant channel impulse response is a factor that the receiver also should be matched to it. Estimation of channel is very important as it causes more complex receiver with matched filter receiver and a complicated processing.

3. *Near-Far problem:* This is one of the major difficulties of DS-CDMA which occurs when many MSs use the channel at the same time, from different distances with uncontrolled transmitted powers. If all mobiles transmit at the same power level, then the powers received at BS will be higher for those near the BS. A fundamental consideration of DS-CDMA is that the transmitted signals should be similar to background noise for the desired received signal at the receiver. This only works if the entire received signals at the receiver are at equal power level. For this reason, mobile users that are near the BS have to transmit at lower power level than mobile users far away. As a result, both signals will be in equal strength level at the receiver (BS) [8]. The near-far effect is shown in Figure 9.

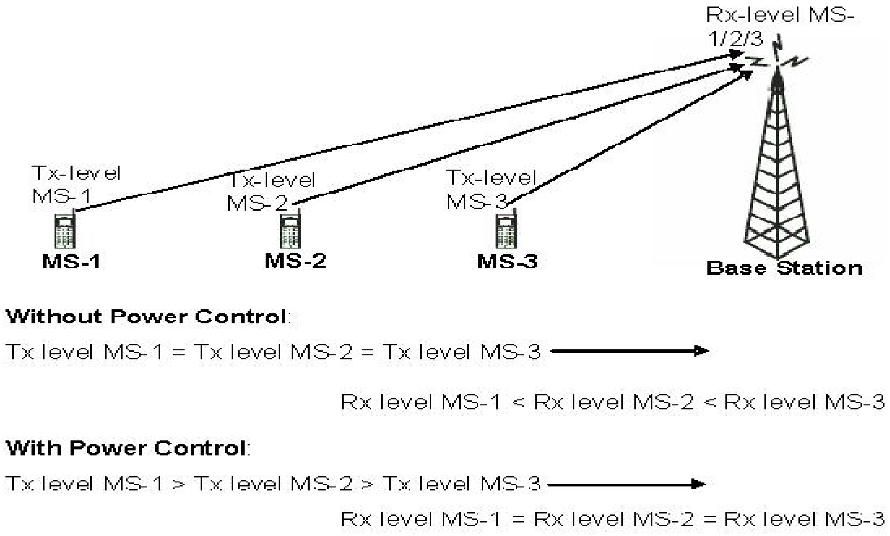

Figure 9. Near-Far problem with and without power control [9]

The Near-Far difficulty is crucial only on the uplink (communication from MS to BS) because on the downlink (communication from BS to MS) the BS transmit orthogonal signals with optimal power simultaneously to users linked with it. In contrast, on the uplink, signals are generated from different distances and locations to the BS within the cell[10]. In an attempt to counteract the Near-Far problem, many CDMA implementations use power control.

2.2 The Downlink Channel

The communication channel to a mobile station from a base station is called a downlink or forward link in a wireless system. In the downlink, all the users' transmitted data are conveyed at the same time by the BS since all of them generate from the same base station. Then, these spread signals will pass through the same propagation path loss, fade and also the same multipath channel simultaneously. Thus orthogonal codes are suitable for using in the downlink channels where the orthogonality[1] of the spreading sequence can be stabilized [6]. There are K users for the downlink in a CDMA channel model is shown in Figure 10. Where $c_k(m)$is the k^{th} user spreading sequence also $b_k(n)$ is the n^{th} bit of the k^{th} active user.

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[1] Orthogonal spreading sequences have zero crosscorrelation if they are completely synchronised. The orthogonality can be retained in synchroneous channels.

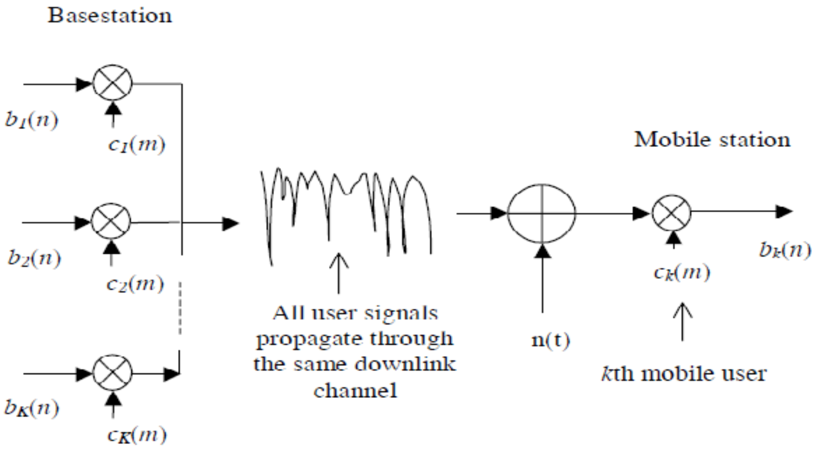

Figure 10. The downlink channel [10]

As mentioned before, at a MS, using the k^{th} spreading sequence, the mobile users can recover the transmitted data by correlating the received signal. That's why orthogonal codes are operated in the forward link. Ideally, MAI is not in the forward link, therefore AWGN will be the prime interference factor. Whenever AWGN is the core disturbance, a user not nearby will be in crucial situation due to large propagation path loss. It should be taken into account that, in multi cell systems (WCDMA), the far awaysignals will suffer from neighbor base stations' interference since users indissimilarbase stations are not reciprocally orthogonal. In this kind of situations, forward link power control is required at the base station so as to enable all far away users to access a higher power communication level than thosecloser to the BS.

2.3The Uplink Channel

Uplink or reverse link are the names given to the communication channel from a mobile station (MS) to a base station (BS). In the reverse link, obtaining synchronous communication from other users is almost impossible because the users transmit their signals from different locations from each other and from the BS. Therefore, as their orthogonality[2] cannot be maintained, orthogonal spreading sequence are not applied in the uplink. Different users' spread signals may result in dissimilar propagations, leading to dissimilar propagation path losses. Moreover, independent fading are caused by unbalance users' signal strength at the BS. Since a no orthogonal codes also unevenly signals strengths in the reverse link, MAI is a severe problem that requires much considerations. Figure 11 explains the uplink DS-CDMA system in a cordless communication channel.

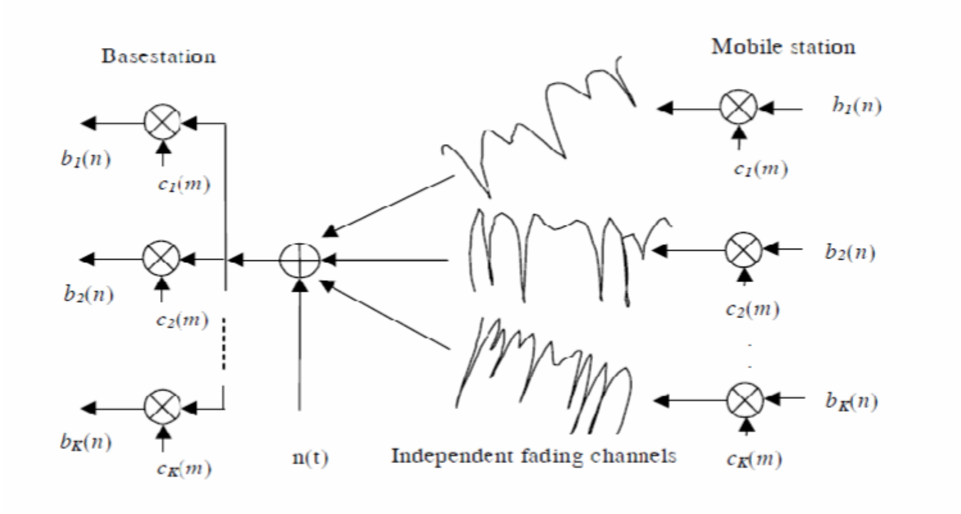

Figure 11. The reverse link channel [10]

At the BS, the k^{th} user restores the original signal by using correlation function between the received signal and the k^{th} user specific code. As a result of non-zero cross correlations between spreading sequences of different users, the k^{th} user will suffer MAI caused by all the other users. If the received strength signal levels at the BS are not identical, a problem arises in CDMA system because the correlating

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[2] Non- orthogonal codes result in non-zero cross correlation. The orthogonality may not be retained in asynchroneous channels.

receiver cannot distinguish weak signals caused by high interference from the other higher signal level. Nevertheless, there are methods to balance the transmitted strength.

2.4 Generation of Spreading Codes

Using high-quality code sequences is essential in CDMA systems to reduce multiuser and multipath interference. So as to overcome the interference, properties of the codes must be designed with the following properties;

1. Every code sequence should be periodic with a distinct length of codeword.
2. Every sequence must be distinguishable from its shifted one.
3. Every code sequence must be recognizable from other code sequences.

Consequently, to design a code sequences for first and second properties, correlation function functions (auto and cross correlation) are applied. Here, the consideration of such function (autocorrelation) is the number of the code periods that the function is to be acquired. Auto correlation is a estimation of how a signal *X(t)* may vary with itself and its time-shifted variance[4]. This function is operated due to calculate the code self-similarity and is defined below:

$$R_{XX} = \int_0^T X(t)X(t+\tau)\,d\tau \qquad (1)$$

The polynomial rings employ maximal linear feedback shift registers. They are also named Maximum Length Sequence (MLS) or pseudorandom (PN) sequences. These sequences are periodic and regenerate each binary code which can be generated by shift registers (i.e. registers of length *m* can generate a code word of length $2^m - 1$. A pseudorandom code is also known as M-sequence. For instance, four stages M-sequence (m=4) generates a code length of 2^4-1= 17). Cross correlation is described as the correlation between two different signals. R_{XY} between two different sequences *X(t)* and *Y(t)*can is define as:

$$R_{XY} = \int_0^T X(t)Y(t+\tau)\,d\tau \tag{2}$$

By applying the autocorrelation and cross correlation functions the spreading code can be singled out.

2.4.1 Pseudorandom Sequences

The M-sequence (or PN sequence) is a binary one with an autocorrelation that over a given time has a high value. As mentioned above, M-sequence also called PN-sequence since autocorrelation of M-sequence and the autocorrelation of band limited white noise have almost the same result. Apart from the fact that PN sequence is unique, it also has multiple appearances that are so identicalto the random binary codes. For exampleit has an almost the same symbol of -1s and +1s,suitablemutual relation between codes,suited formutual relation between the delayed forms of the codes, etc. By applying sequential logic circuits the PN sequence is usually generated. A feedback shift register is illustrated in Figure 12.

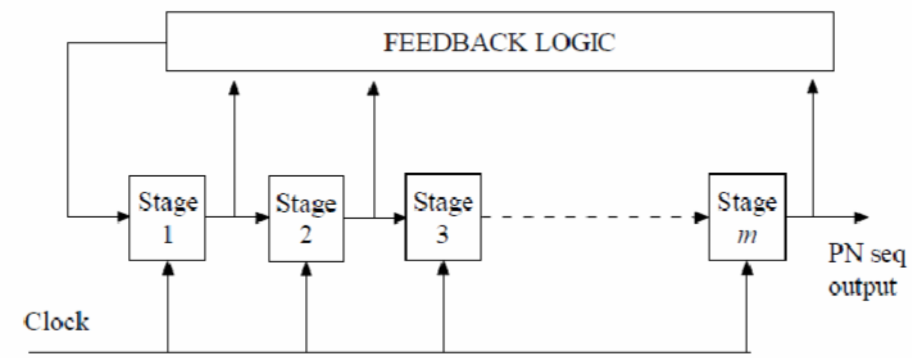


Figure 12. LFSR (*m*-stages) [5]

As illustrated in the diagram above, binary codes are shifted over the shift registers with specific synchronous clock generator. The outcomes of the differentstages are logically processed and provide feedback for the first stage's entry. This type of shift register is referred to as a linear PN code creator.

Pseudorandom Noise (PN) or (M sequence) generators are commonly at the main part of every DS-CDMA system. They should be applied in order to perform synchronization and uniquely distinct codes to each user through passing the transmission interface. There are multipleamalgamations of taps whichgeneratetiny cross correlation PN codes. Hence, this may be described as a group of taps which generate a set of low cross correlation PN codes for a distinct length shift register. Walsh, Kasami and Gold were proposed the recognition of trivial cross correlation MLS.

Gold in 1967 and 1968 offered his own codes which is created by EXOR-ing two *M* sequences of equal length. Figure 13 shows a Gold code generator.

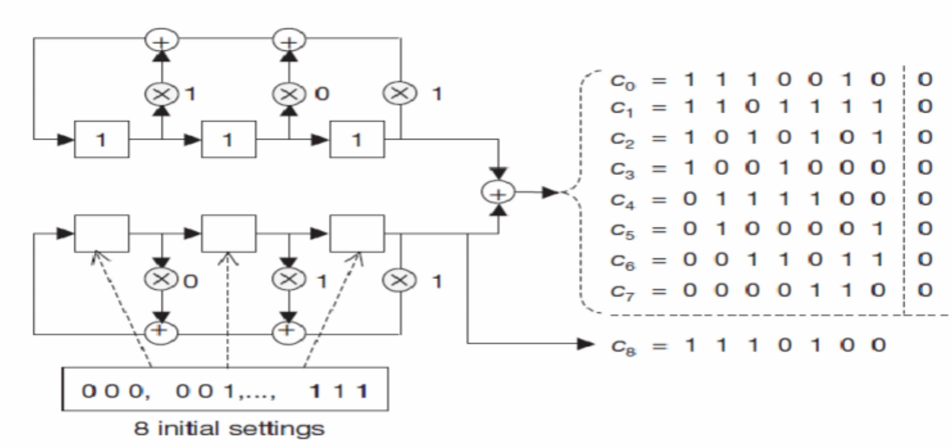


Figure 13. Gold Code Generator (via XOR-ing two *M* sequences)

Gold sequences have better cross correlation properties compared to M sequences providing that LFSRs are organized appropriately. However, cross correlation value of Gold sequence is not zero in synchronized area. Figure 14 shows that the increasing number of users will affect the performance of the CDMA system.

So, there is another type of Gold code with zero value of cross correlation at synchronous situations which is called orthogonal Gold sequence. One chip is added to Gold sequence to obtain an orthogonal Gold code sequence. In the two following figures, orthogonal Gold sequence is compared to the Gold sequence. It is certain that, although the number of users has risen in a cell, the performance of a system via orthogonal gold sequence still is perfect and Figure 15 shows this fact clearly. Nevertheless, Gold sequence is one of the highly used codes in cellular mobile environment. Gold sequences are applied through this thesis.

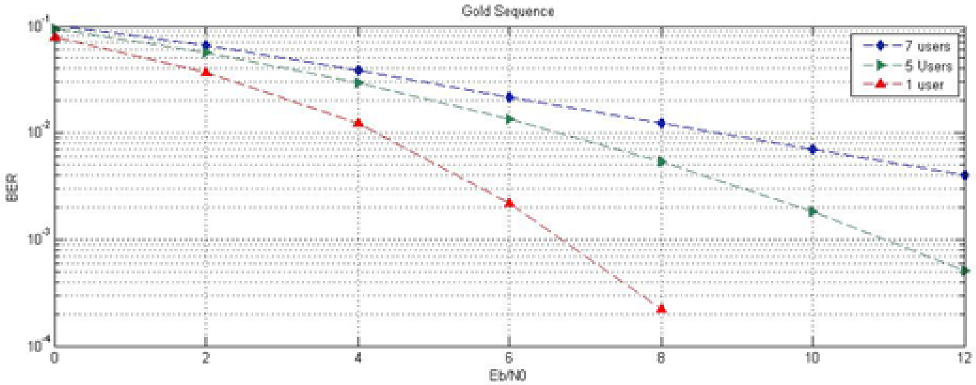


Figure 14. BER vs. E_b/N_0,

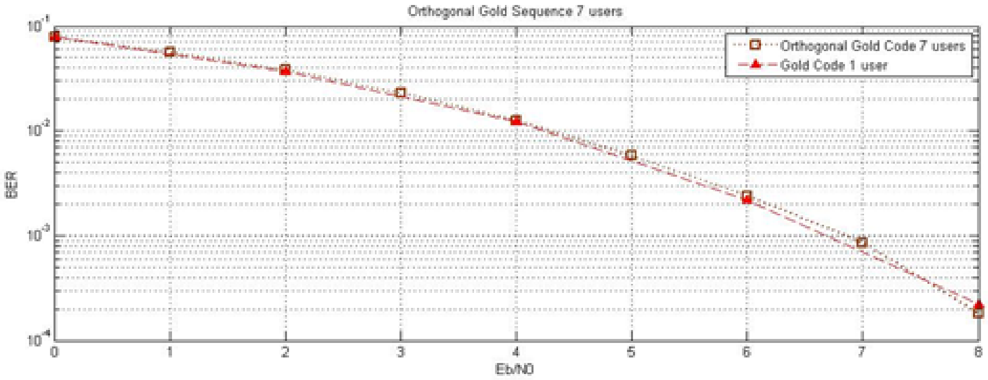


Figure 15. BER vs. E_b/N_0, Comparison of Gold codes and orthogonal Gold codes.

2.5 The Mobile Wireless Channels

In this thesis two communication channel models will be used: AWGN and fading channels [11], [12].

2.5.1 Additive White Gaussian Noise (AWGN) Channel

The thermal noise n(t) is a term which denotes undesired electrical signal that always occurs in electrical communication systems. The thermal noise caused by motion of electron in all dispersed electrical elements. The effect of thermal noise leads to AWGN [13]. It can decline the receiver capability to restore users' data. The term additive refers to this fact that, the noise is always superimposed and added to the transmitted signal. From a mathematical aspect, thermal noise is denoted by a zero-mean *Gaussian* random original user signal $a(t)$and AWGN signal $n(t)$:

$$Z\,(t) = a(t)+n(t) \tag{3}$$

where power density function for Gaussian noise can be characterized as below:

$$\frac{1}{\sigma\sqrt{2\tau}}\,EXP\left|-\frac{1}{2}\left\{\frac{z-a}{\sigma}\right\}^{2}\right] \tag{4}$$

where σ^2 is the variance of variable n. Also, thermal noise power spectral density $G_n(f)$is a uniform distribution in entire frequencies, and a simple model is shown as:

$$G_n\,(f) = \frac{N_0}{2} \tag{5}$$

The factor of 2 shows that, $G_n(f)$ is a dable-sided PSD. Noise power with a flat spectral density is known as white noise because thermal noise appears in every communication systems. Gaussian distribution is commonly applied to the noise in communication systems.

2.5.2 Mobile Radio Propagation Channel

In a wireless cellular system, a signal communicated over a cordless channel may suffer problematical propagations which include diffraction, multiple reflections and scattering. Figure 16 shows a connection between an MS and a BS.Because of, mostly crowded propagation situations between the BS and the MS, a line-of-sight (LOS) path may almost not be accessed.

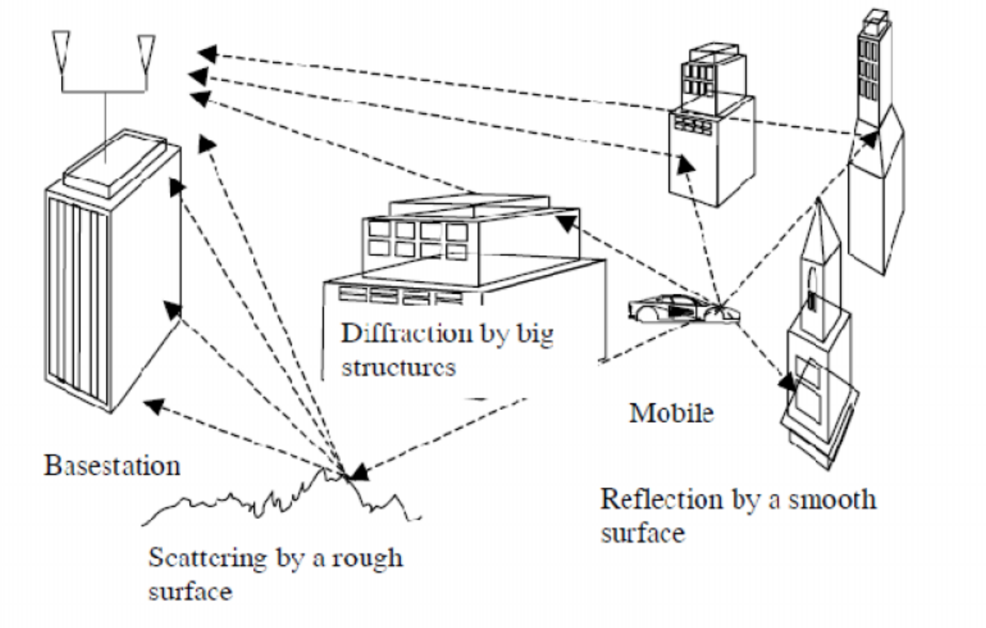


Figure 16. Wireless propagation [10]

Received signals at the BS are completely an amalgamation of different amplitudes phases and paths. Some advantages and disadvantages may arise from superposition of these paths under condition of the different phases among the entire received paths. Also, if the area and MS are not movable, the detected signal at an arbitrary location will be fixed. Given that a user continually changes positions, the multipath will be more complicated. The variation of received signal is the same as variation of time function. Apart from the received signal also declines gradually due to increasing distance between the transmitter and receiver (TR). The signal degradation also possibly varies from region to region. As a result, a signal broadcasting over a mobile channel may experience an enormous degradation, and multipath fading. The propagation loss that is almost constant through a vastregion is known as Large Scale propagation loss.Commonly characterized in terms of the average path and its fluctuations around the average. Apart from the propagation loss alternates proportionally in a small area, it is called as Small Scale (simply fading) propagation loss. It states rapid fluctuations of signal phase and amplitude because of the multipath occurrences. Fading propagation pattern is significant to clarify the influence of multipath propagation [14].

2.5.3 Fading Channel

At the receiver, different received signals experience dissimilar categories of fading. It may either relate to the channel parameters like delay spread and Doppler spreador data parameters such as bandwidth. The frequency and time dispersion mechanism in a telecommunication channelslead to four probable specific effects. These are determined by the relation of the velocities, the channels, and the transmitted signals. Multipath delay spread signal leads to flat and also frequency selective fading while Doppler spread signal results in fast and slow fading. Figure 17 illustrates these categories of fading as a tree chart [14].

2.5.3.1 Fading Types Based On Multipath Delay Spread

Delay spread is a factor that defines the dispersal nature of the channel in local areas. The time dispersal properties of CDMA systems are quantified by their root mean square (RMS) delay spread and mean excess delay. Time dispersion multipath leads the transmitted signal to experience either frequency selective or flat fading [14]:

i. *Flat Fading*: When the cordless communication channel has a linear phase response and a consistent gain through a bandwidth that is larger than bandwidth of the transmitted signal, then the received signal will experience flat fading. The strength of the received signal varies with time, due to variations in the gain of channel affected by multipath. Thus, varying the channel gain causes changing the amplitude of received signal. Furthermore, a transmitted signal experiences flat fading in one of two circumstances; either its bandwidth is much less than the channel bandwidth, or if the RMS delay spread is much less than its chip period.

ii. *Frequency Selective Fading*: When a channel holds linear phase response and a consistent gain over a bandwidth that is smaller than the bandwidth of the transmitted signal, then the transmitted signal will experience frequency fading [14]. In frequency selective fading, the detected signal consists of many forms of the transmitted signal that are delayed and attenuated in time; therefore, the signal is distorted. Moreover, a received signal experiences frequency selective fading whether its RMS delay spread is much greater than its chip period or its bandwidth is much greater than the channel bandwidth.

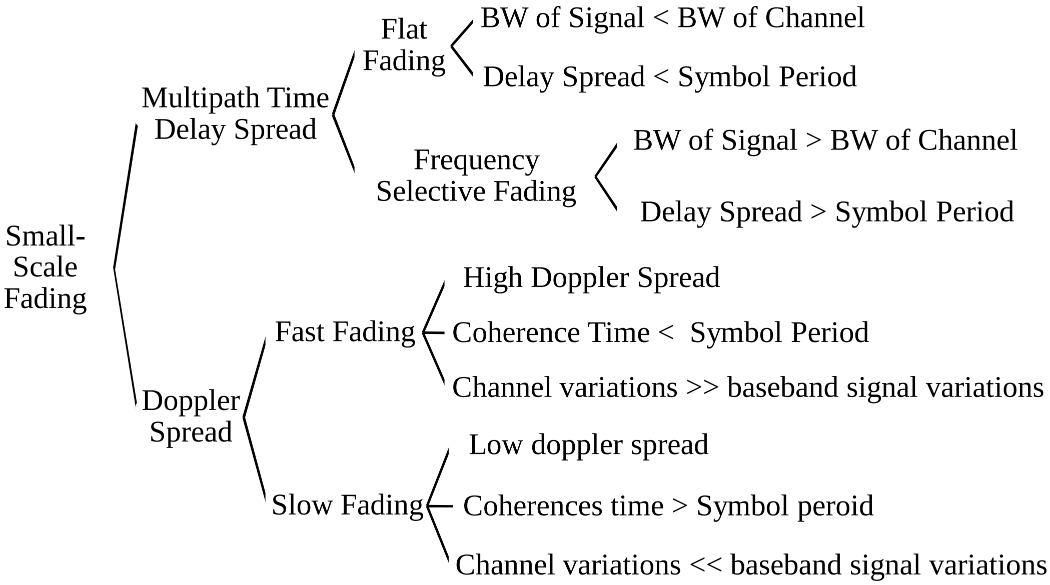


Figure17. Type of different fading [14].

2.5.3.2 Fading Type Based On Doppler Spread

Evaluation of the spectral broadening affected by the time rate of the wireless communication channel is Doppler spread, and is described as the range of frequencies where by the received Doppler spectrum is fundamentally non-zero[14]. The amount of spectral broadening is influenced by Doppler frequency shift (f_m) where f_m is

$$f_m = \frac{v\, f_c}{c} \tag{6}$$

Where c, v and f_c correspond the speed of light, the speed of traveling, and the centre frequency, respectively.

Coherence time T_c is a statistical measure of the phase through where the channel impulse response is essentially invariant [15]. T_c is given by

$$T_c \approx \frac{1}{f_m} \tag{7}$$

The channel is named as fast fading or slow fading channel due to how fast the transmitted signal changes as compared to the rate of change of the channel:

i. *Slow Fading:* Here, the channel impulse response depends on a rate much slower than the received signal [14]. The channel is supposed to be static over one or more reciprocal bandwidth interval in frequency dominion in slow fading channel. Consequently, a signal goes through slow fading when its symbol period is way lower than T_c, and its transmitted bandwidth is much larger than the Doppler spread.

ii. *Fast Fading*: Here, the channel impulse response varies fast within the symbol duration [14]. For fast fading, the coherence time of the channel is smaller than the chip period of the received signal. Thus resulting to frequency dispersion due to Doppler spreading. Therefore, a signal experiences fast fading if its symbol period is greater than T_c, and its transmitted bandwidth is less than Doppler spread.

2.5.4 Rayleigh Fading

The Rayleigh distribution is commonly used to illustrate the envelope of an individual multipath component, or the statistical time varying nature of the received envelope of a flat fading signal in mobile radio channels [14]. Mathematically, the Rayleigh distribution has the probability density function below (pdf):

$$P(r) = \frac{r}{\sigma^2} e^{(\frac{r^2}{\sigma^2})} \tag{8}$$

Where r^2 is the instantaneous power, σ^2 is the variance of the transmitted signal, and σ is the RMS value of the transmitted signal power before envelope detection. This process happens where there is no LOS (line-of-sight) path between transmitter and receiver antennas (TR). The equivalent cumulative distribution function (CDF) is given by [16].

$$P(r) = P(r \leq R) = \int_0^R P(r)dr = 1 - \exp\left(-\frac{R^2}{2\sigma^2}\right) \tag{9}$$

In this research, Rayleigh model will be used for the fading channel. Meanwhile, Jakes method [17] is used for the Rayleigh fading channel simulation.

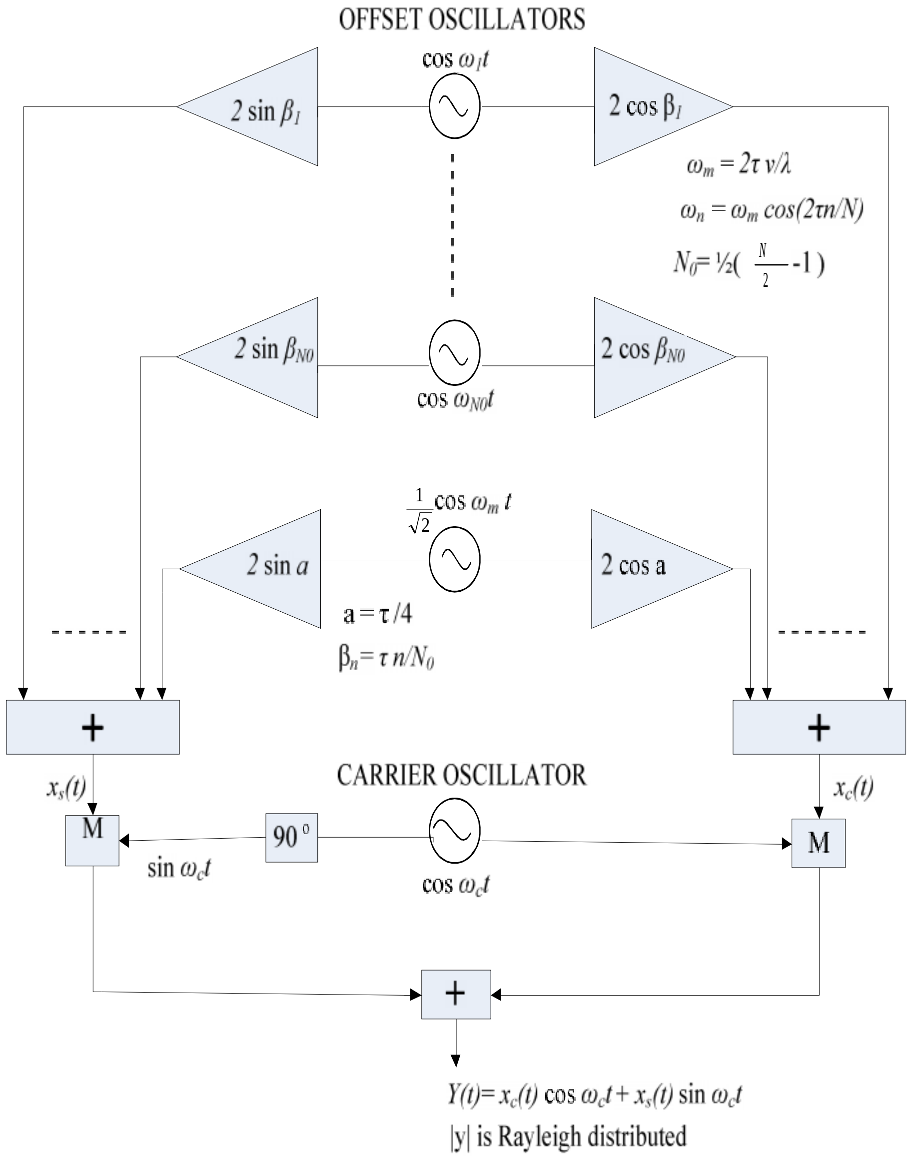


Figure 18. Simulator that duplicates a mobile radio spectrum [17].

Chapter 3

POWER CONTROL IN DS-CDMA

3.1 Power Control (PC)

In wireless communication systems, power control (PC) has a major effect in the quality of service (QoS) and the channel capacity. This is particularly true in CDMA cellular systems since the entire mobile stations (MSs) share a common channel thus the power of each mobile must be keenly monitored to avoid unnecessary interference.

Some studies which have considered the relation between interference and system capacity in a standard fading model was done in [29].

In CDMA, PC is applied to maintain the Near-Far problem and to decrease the effect of multiple access interference (MAI). In DS-CDMA, every user is allotted a specific spreading sequence to distinguish users that share the same radio channel. Due to non-zero cross correlations between codes, MAI is bound to occur and thus becomes undesirable for any target user. When the users’ transmitted powers are not controlled, a distant user who transmits signals to the BS at a low level will suffer as a result of the MAI from the closeby user whose signal strength is high [18]. In addition, the average received power at the BS may also fluctuate slowly as a result of the effect of shadowing. Thisoccurs when a MS is travelling over different environments. PC plays an important role to decline the effects of multipath fading.

Multipath fading cause uncorrelated signals between forward link and reverse link channels and in dissimilar carrier frequency bands. The PC procedure in CDMA systems is more complex than that in time division and frequency division multiple access systems due to the MAI complication in CDMA systems. PC attempts to moderate the impact of deep fades. If concurrently a user experiences a deep fade and where it is required to raise transmission power, the user's transmission power will affect the Signal-to-Interference ratio (SIR)suffered by other users. This scenario may affect the system stability because each user will increase its transmission power in order to get the desired power level. Consequently, all users will increase their power and therefore inter-cell interference will occur [10].

PC is used by each BS in a DS-CDMA cellular system to set the transmitted powers in appropriate level for efficient communication performance. Using PC enables the user to transmit the adequate level of power. The PC algorithm is also planned at monitoring the users' transmit strength to control their mean received strength at the BS to be identical. Thus, PC should be applied together with another device which can decline the weight of deep fades [19]. Some advantages of using PC in DS-CDMA system are listed as below:

- Overcoming the near-far effect.
- Reduce MAI and inter-cell interference.
- Maximize the capacity of the overall cellular system.
- Decrease the user's power consumption.
- Increase the battery lifetime.

3.2 Uplink versus Downlink Power Control

3.2.1 Power Control in Downlink

On the BS-to-MS link or downlink channel (forward link), the spread signals for the entire MSs created from the same BS and simultaneously are transmitted through the same channel. Therefore the entire signals transmitted by a particular BS and propagate over the same channel and undergo the similar attenuation before reaching the MS. Orthogonal codes can be utilized in theforward link channel. There are theoretically no MAI and Near-Far problems in the forward link when orthogonal sequences are used. Therefore, via orthogonal spreading sequence, there is no longer any crucial problem and no PC is required in single cell systems. In multiple cell systems, moreover, PC in forward link is essential in order to rectify the users at boundaries of the cell. These users may experience interference from neighbour cells since users in dissimilar cells are not mutually orthogonal from each other [20].

Interference from an adjacent cell fades independently from the given cell and may degrade the system performance. If this happens forward link PC is required to prepare adequate power level for bordered users suffering from high interference. As such appropriate transmission powers can minimize the interference of nearby cells. This process is prepared at the BS by allowing the distant users to transmit at higher level than those located near the BS. PC is required in forward link in order to equalize and control the ICI to the heavily loaded cells. This also reduces the co-channel interference cells by upgrading the necessary transmission power level.

3.2.2 Power Control in Uplink

In CDMA, the uplink transmission may suffer a near-far difficulty if power control is not used. In the MS-to-BS link or uplink (reverse link), different users transmit their signals at different times and from different locations. Synchronization is often very difficult and almost impossible to set. Due to missing synchronization, orthogonal spreading sequences may not be applied in the reverse link as their orthogonality will fail. Moreover, MS signals spread over dissimilar radio channels and they are prone to dissimilar propagation path mechanisms with independent fading. Therefore different fading channels lead to unequal received power level at the BS. This therefore hinders us from using orthogonal spreading sequences. Due to unequal received power levels in the uplink that influences of MAI and Near-Far problem becomes evident. The fundamental problem in uplink is the Near-Far problem. Strong interference reduce the power level of bordered users. In fact, the Near-Far problem is the principal shortfall for DS-CDMA as compared to other CDMA types (e.g. frequency hopping). If detected strength levels at the BS are not the same, the relating receiver cannot be able to distinguish the weak user’s signal because of other users with higher power levels disturbance [18].

Thus, uplink requires the use of PC to modify the transmission powers and compensate the varying channel attenuations, in order that signal from different MS are received with the same powers at the BS. Therefore, PC is the basic requirement in the reverse link of DS-CDMA system. It is very important to be able to keep the disturbance acceptable for all users and get important capacity progress in DS-CDMA systems. Due to the importance of PC in MS-to-BS link, PC at uplink will be investigated in this thesis.

3.3 Power Control Algorithms

There are several proposed methods of power control algorithms that were suggested recently. PC techniques can be categorized in many different aspects.

Here, two most important algorithms, namely open-loop power control (OLPC) algorithm and closed-loop power control (CLPC) algorithm, will be described.

3.3.1 Open Loop Power Control (OLPC)

An appropriate OLPC can be applied to conquer the Near-Far and shadowing problems on the uplink of a CDMA system [21]. The OLPC is planned to confirm that the received strengths from entire users are on average the same at the BS. In the OLPC algorithm, the MS can calculate the necessary transmitted power by applying an approximation power level from the forward link signal. Hereby, there is no use for a feedback loop from MS to BS. The reason is that, the large-scale propagation loss is reciprocal between forward and reverse link channels. Figure 19indicates how an OLPC algorithm manages the near-far problem in the uplink.

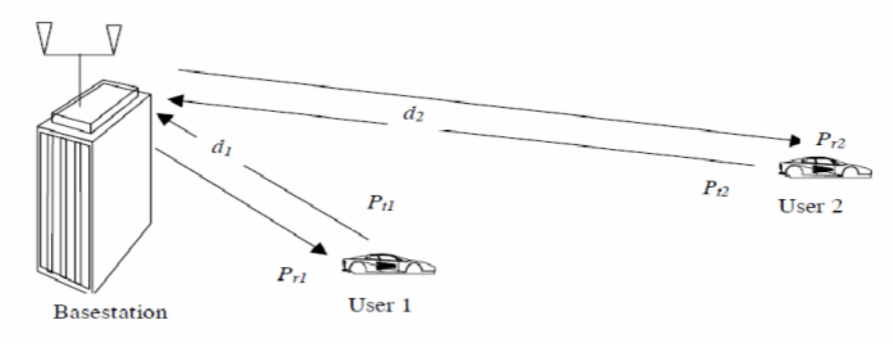


Figure 19. Open-Loop Power Control [10].

In other words, this type of PC algorithm works if the up and down links are correlated. It is worth mentioning that although an OLPC can modify effect of shadowing and the Near-Far. However, multipath fading channel can still decline the performance of system [10]. For this reason, there is a requirement for a CLPC which will modify the necessary transmit power.

3.3.2 Closed Loop Power Control (CLPC)

As mentioned before, CLPC is more important on the uplink than on the downlink because on the down link, synchronous transmission is possible and orthogonal code can be utilized. CLPC aims at excluding the received signal fluctuation because of fading. CLPC is based on a feedback procedure. This design of power control is utilized when the MS is active. The BS is continuously monitoring the uplink. If the quality of the uplink falls to an unacceptable level, then the BS commands the MS to modify its power level. For one to modify the fading in theuplink, the reverse link channel information has to be estimated at the BS and then sent back as a feedback command to the MS. The MS can then correct its transmission power according to the feedback information.

Figure 20. CLPC [22].

In CDMA systems CLPC to control multipath fading has been considered in several studies. Simulation of PC, based on received signal strength at the BS is studied in this thesis is described in [23].Those based on combined SIR with signal strength measurements and signal to interference ratio (SIR) discuss in [24].

3.4 Power Control Computation

Power control measurements may be categorized in to several classes according to the variable that is measured to evaluate the power level [25]: bit-error-rate-based (BER-based), signal-to-interference-based (SIR-based), and strength-based are more well-known than the others. Bit-error-rate is the element of controlling the power in BER-based PC method. BER is defined as an average number of missed bits compared to original sequence of bits [14].In signal-to-Interface-ratio based PC, the measured element is signal-to-noise-ratio (SIR) where disturbance includes channel noise and multi-user interference. A critical aspect regarding SIR-based PC is the probability of occurrence of positive feedback. Positive feedback arises in a situation where one mobile has to increase its transmission power to prove the desired SIR toward the BS. Nevertheless, the increase in its power also causes an increase in interference to other MSs so that others are also obliged to increase their power. Also in strength-based PC schemes, the strength of a received signal at the BS from a MS is the factor that defines whether it is higher or lower than the appropriate strength level. Thereafter, the command will be sent from the BS to rectify the transmission power level accordingly. It should be noted that two types of PC updaters exist. The first type could be identified as those that are fixed in the transmission power step size (known as fixed step size type), and those that are adapted to the channel variation in the transmission power step size (known as adaptive step size method).

Specific samples of fixed and adaptive step size methods are the fixed step size algorithm and the inverse update algorithm used by Chokalingam in [26]. In this thesis, the strength-based type which uses a fixed step-size algorithm similar to the one in [10] and[27] isstudied through simulations. A specific CLPC algorithm via a fixed-step size (CLPC-FS) is applied in this work. This algorithm is similar to[26].

The algorithm will be further analysed. In communication, MSs are in different situations among themselves and their BS's. They may either be close or far away from the BS. So without any PC algorithm, their transmitted power will not be at the same level. As mentioned before, it is a fundamental problem in DS-CDMA system which needs to consideration via applying an appropriate PC algorithm.

The transmit power of MSs are signified byE_b/N_0(energy per bit to noise variance ratio).If an MS is far away from the BS, E_b/N_0 is taken to be less than the desired E_b/N_0. In contrast with, if an MS is so close to the BS, E_b/N_0 is taken to be higher than the desired E_b/N_0. Since when a MS moves far apart from the BS, the power received from the mentioned MS drops dramatically. There also can be some path losses and shadowing which will result in reduced power level received at the BS.

For simplicity, the CLPC-FS algorithm is presented in matrix format. First of all, the desired power (P_d) should be determined. The P_d is the power level which denotes the desired BER (BER for the perfect PC algorithm). At the end of the process, the whole MSs should be in the P_d level. As such, the Near-Far problem will be reduced. Thereafter, the transmitted power of every MS will be measured by applying the following formula:

$$\begin{bmatrix} p_t(1) \\ \vdots \\ p_t(i) \\ \vdots \\ p_t(K) \end{bmatrix} = \begin{bmatrix} \frac{E_b}{N_0}(1) \\ \vdots \\ \frac{E_b}{N_0}(i) \\ \vdots \\ \frac{E_b}{N_0}(K) \end{bmatrix} = \begin{bmatrix} A_b^2\,(1) \\ \vdots \\ A_b^2\,(i) \\ \vdots \\ A_b^2\,(K) \end{bmatrix} \qquad (1)$$

where$p_t(i)$,$A_b^2\,(i)$, andE_b/N_0(i) denote the transmitted power, bit amplitude, and E_b/N_0 of the i^{th} MS respectively. K denotes the number of MSs in the system. To calculate the received powers at the BS, the estimates of the dispread values are used. Despread values are the consequence of process, and they are applied to choose whether the received bit is 0 or 1. Before decision the value of the received bit, the despread values are used to obtain the received power of each user as follows:

$$\begin{bmatrix} p_r(1) \\ \vdots \\ p_r(i) \\ \vdots \\ p_r(K) \end{bmatrix} = \begin{bmatrix} \frac{D^2}{G}(1) \\ \vdots \\ \frac{D^2}{G}(i) \\ \vdots \\ \frac{D^2}{G}(K) \end{bmatrix} \tag{2}$$

where $p_r(i)$ denotes the received power at BS and $D(i)$ represent the despread values of the i^{th} MS. G is used to symbolize the processing gain which is also known as code length. So far, the steps of providing $P_{d'}$, $P_t(i)$, and $P_r(i)$, are mentioned to propose the variables which are applied in CLPC-FS algorithm. Figure21 illustrates the flowchart of the CLPC-FS.

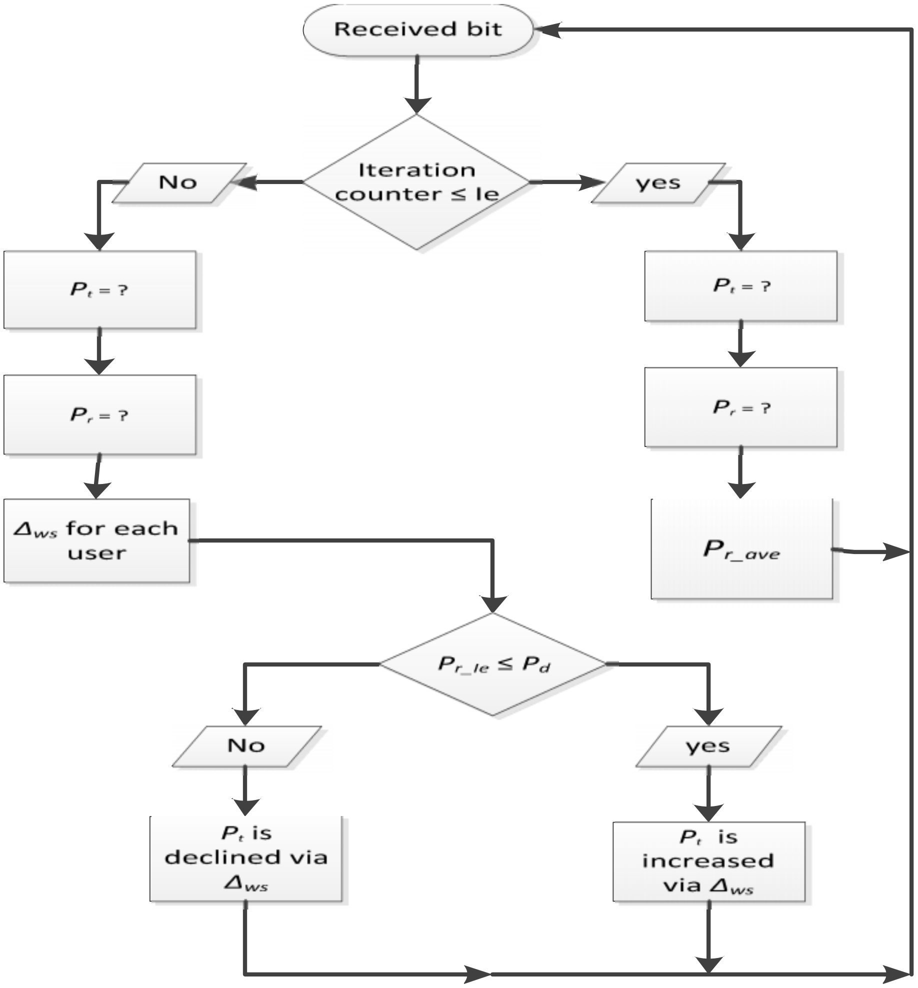


Figure 21. CLPC flowchart

The figure shows that, there is a parameter called estimation interval (I_e). Estimation interval is the bounds for number of bits used for averaging. Moreover, I_e is the number of times that the transmitted and the received powers should be computed in order to perform averaging operation. Before the estimation interval is reached, received powers are stored for each user. Then by applying these stored powers as an average received power ($P_{r\text{-}ave}$) is computed for each user. $P_{r\text{-}ave}$ is given by

$$\begin{bmatrix} P_{r\_av}(1) \\ \vdots \\ P_{r\_av}(i) \\ \vdots \\ P_{r\_av}(K) \end{bmatrix} = \begin{bmatrix} \frac{\sum_{j=1}^{I_e} P_r(1,j)}{I_e} \\ \vdots \\ \frac{\sum_{j=1}^{I_e} P_r(i,j)}{I_e} \\ \vdots \\ \frac{\sum_{j=1}^{I_e} P_r(K,j)}{I_e} \end{bmatrix} \tag{3}$$

where $P_{r\text{-}ave}$ shows the mean received power of the i^{th} MS. In equation 3, $P_r(i,j)$ is the average received power of the i^{th} MS in the j^{th} iteration. The limit for j is I_e which is the approximation interval used for averaging. I_e can be altered to get maximum performance. When $P_{r\text{-}ave}$ is computed, a specific window size (S_w) is preferred to be able to calculate the step size (Δ_{ws}). The window size is the number of iterations that will be completed in order to get the P_d (e.g. if S_w is 20, the P_d will be achieve after 20 iterations). Also, S_w can be altered to get the maximum result. The effects of S_w and I_e on CLPC-FS will be examined in the simulation chapter. The step size of each MS is computed by

$$\begin{bmatrix} \Delta_{ws}(1) \\ \vdots \\ \Delta_{ws}(i) \\ \vdots \\ \Delta_{ws}(K) \end{bmatrix} = \begin{bmatrix} \frac{P_{r\_av}(1)-P_d}{S_w} \\ \vdots \\ \frac{P_{r\_av}(i)-P_d}{S_w} \\ \vdots \\ \frac{P_{r\_av}(K)-P_d}{S_w} \end{bmatrix} \tag{4}$$

Where $\Delta_{ws}(i)$ denotes the step size which will be apply to fall or rise i^{th} MS's transmitted power consequently. From equation(4), the step size Δ_{ws} is acquired by subtracting the P_d from $P_{r\text{-}ave}$ and dividing this estimate by window size S_w . It must be noted that, Δ_{ws} is computed only once, not for every iteration. When Ie is reached (current iteration maybe less than or equal to I_e), this estimate is done. Nevertheless, after this iteration, Δ_{ws} is constant for all iterations. Hence Δ_{ws} forms the basis of this CLPC-FS algorithm. Decreasing or increasing the transmitted power by Δ_{ws} depends on the selected window size S_w (e.g. if S_w is chosen to be 50, the desired

BER will be reached in 50 iterations). Now, the new transmitted power p_t* is obtained by

$$\begin{bmatrix} P_t^*(1) \\ \vdots \\ P_t^*(i) \\ \vdots \\ P_t^*(K) \end{bmatrix} = \begin{bmatrix} p_t(1) - \Delta_{\mathrm{ws}}(1) \\ \vdots \\ p_t(i) - \Delta_{\mathrm{ws}}(i) \\ \vdots \\ p_t(K) - \Delta_{\mathrm{ws}}(K) \end{bmatrix} \tag{5}$$

where $P_t*(i)$ denotes the new transmitted power of the i^{th} user. This power is then applied to determine the amplitude factor. As it can be inferred from equation 5, when Δ_{ws} is positive, the ex-transmitted power P_t will be decreased by Δ_{ws} to reach the desired power level (P_d). On the other hand, when Δ_{ws} is negative, P_t will be increased by Δ_{ws} to reach P_d. Before reaching P_d. the transmitted power which is better than P_t but worse than P_d , is called P_t* where P_t* is applied to calculate the amplitude factor F_a of each user by using

$$\begin{bmatrix} F_a(1) \\ \vdots \\ F_a(i) \\ \vdots \\ F_a(K) \end{bmatrix} = \begin{bmatrix} \sqrt{P_t^*(1)} \\ \vdots \\ \sqrt{P_t^*(i)} \\ \vdots \\ \sqrt{P_t^*(K)} \end{bmatrix} \tag{6}$$

where $F_a(i)$ signifies the amplitude factor which will be used in multiplication process of i^{th} MS. As a last step in one iteration, the new coming antipodal bits are multiplied with the amplitude factor. These bits are subsequently sent through the channel to be used in the next iteration to provide a better estimation of transmitted power. At last, the desired power and desired BER will be reached approximately for all users.

Chapter 4

SIMULATION RESULTS

In the previous chapters, it was stated that, power equality at B.S. isimportant to resolve the Near-Far problem in a DS-CDMA system. Hence, in order to compensate the transmitted powers of all users, applying a power control algorithm is inevitable in CDMA systems. This particular chapter presents the simulation results for a Direct Sequence-Code Division Multiple Access (DS-CDMA) system. Effect of Closed loop Power Control (CLPC) in DS-CDMA system is considered. In order to avoid complexity, BPSK modulation is used. Gold code sequences are used to spread the users' signal, Monte Carlo simulation method is employed.

First, a system without CLPC in different scenarios is examined. Then the mentioned system is compared with a system which uses CLPC in its algorithm. In addition, a system with some new parameters otherthan the previous simulations is briefly examined in the end of this chapter.

4.1 A System without CLPC

4.1.1 Half of the Users with Reduced Transmitted Power

In this section, it is assumed that users are divided in two groups. Half of the users transmit unacceptable power levels compared to the other users. The first group of users transmit 2 dB less than the second group. Consequently total received powers of users at the B.S. are unbalanced. This problem affects BER. An acceptable

CDMA system needs to have equal received power levels at B.S. and a power control algorithm is required.

The simulation is done with 10000 bits for each 30 users (K) in AWGN channel and the power factor (M) is 31. Figure 22 illustrates the precision of simulation for an unbalance power DS-CDMA system as described in this section. It should be mentioned that, figure 22 is the only figure in this chapter that simulates Near-Far-Ratio in 2dB difference among users. In order to show the effect of PC better, the Near-Far-Ratio (NFR) will be set at 5dB.

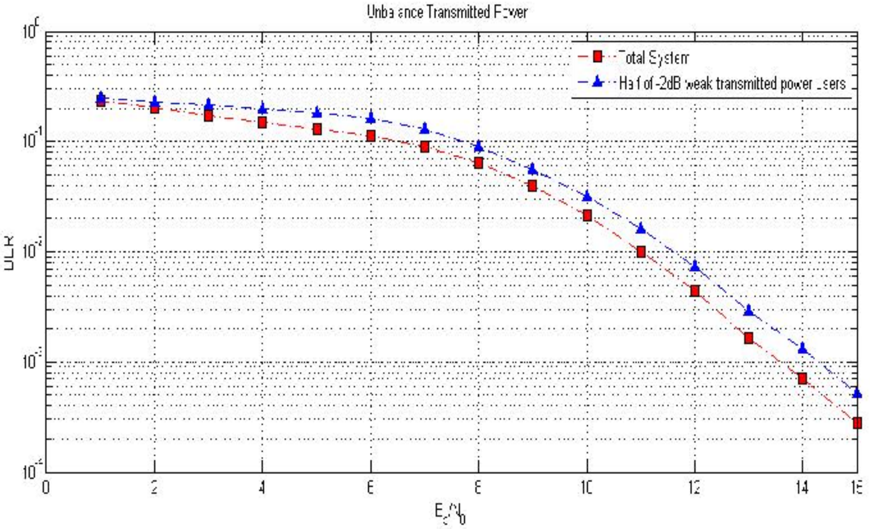


Figure 22. E_b/N_0 vs. BER for a system with power imbalance.

(Gold code, NFR=2dB, M=31, K=30).

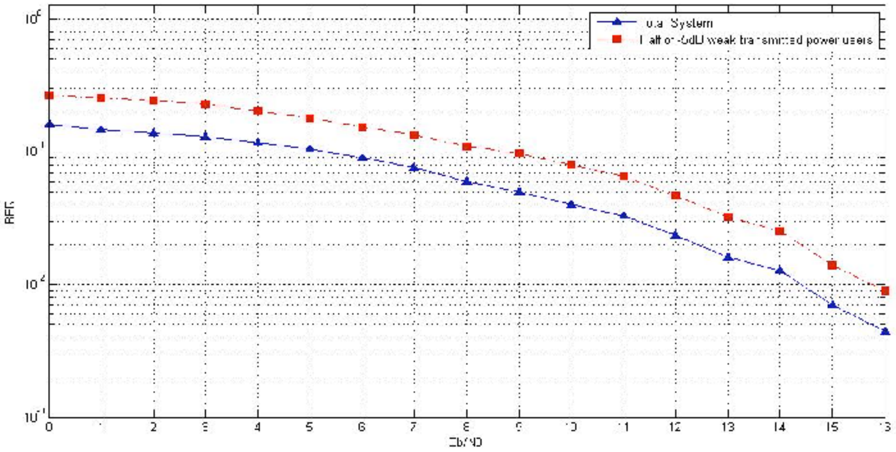


Figure 23. E_b/N_0 vs. BER for an unbalanced power transmitted system where half users are transmitted -5dB less than the other users. (Gold code, NFR=5, M=31, K=30).

It is clear that, with bigger NFR between two groups of users (weak users and strong users), the simulation results will show larger in performance. This fact is clearly shown by comparison of figures 22 and 23. In fig. 22, at BER $=10^{-1}$there is a 2 dB gain in performance whereas in fig. 23, at the same BER there is a 4 dB gain in performance between the strong and weak users.

As seen from Figure 24 without applying an appropriate power control algorithm, despite the increasing E_b/N_0, received powers at B.S., will not reach the same level and will cause increased MAI at the detector. Hence, the performance of CDMA system will be reduced drastically.

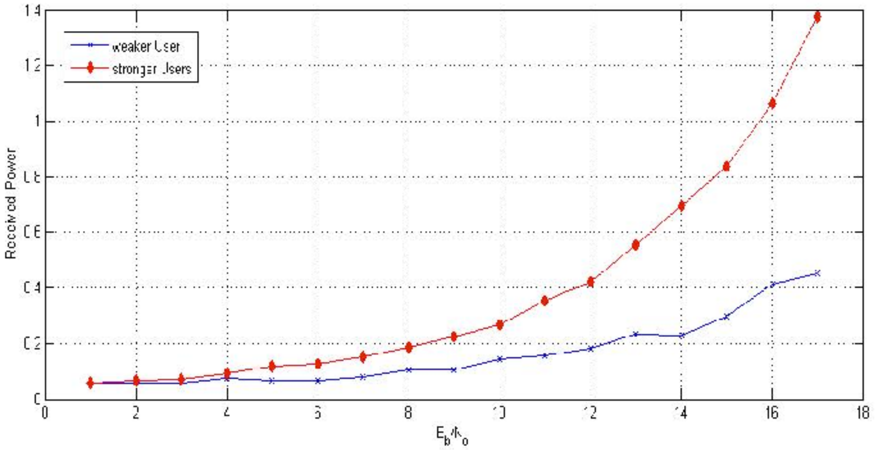


Figure 24.E_b/N_0vs. Received Power for an unbalance power transmitted system where half users are transmitted -5dB less than the other users. (Gold code, NFR=5, M=31, K=30).

4.1.2 The Desired User with Unbalanced Transmitted Power

In this section it is assumed that all users have the same power level at the B.S., except the desired user who transmits -5dB less than the other users in the system. The simulation results in this section show that, although most users transmit at the same power level, still the desired user with unbalanced transmit power influences the system's performance. This is because the desired user's transmit power is lower than the acceptable level. The receiver unit treats the received power of the desired user as noise and it tries to reduce it.

The simulation in figure 25 is done for 10 users (K) with 10000 bits for each user and the processing gain (M) is 31. AWGN channel model is used. Figure 25 illustrates the effect of unbalanced transmitted power scenario which was described in this section.At a BER = $10^{-1}$the desired user performs 2.2 dB is worse than the rest of the users.

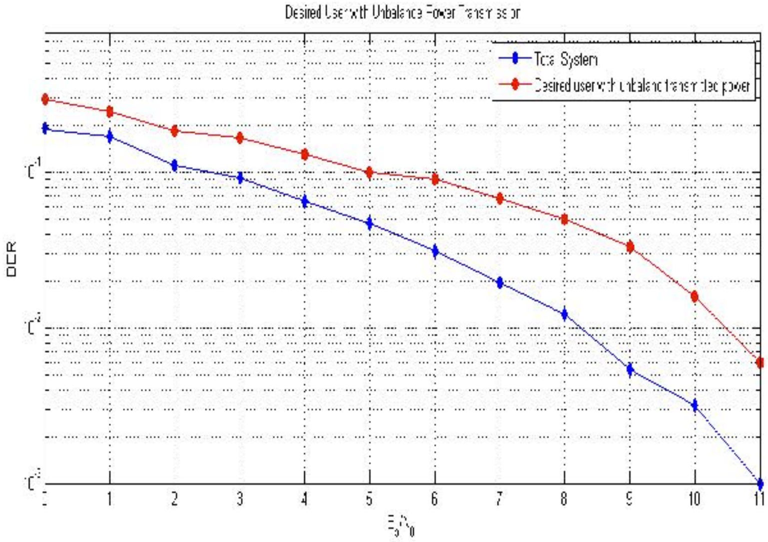
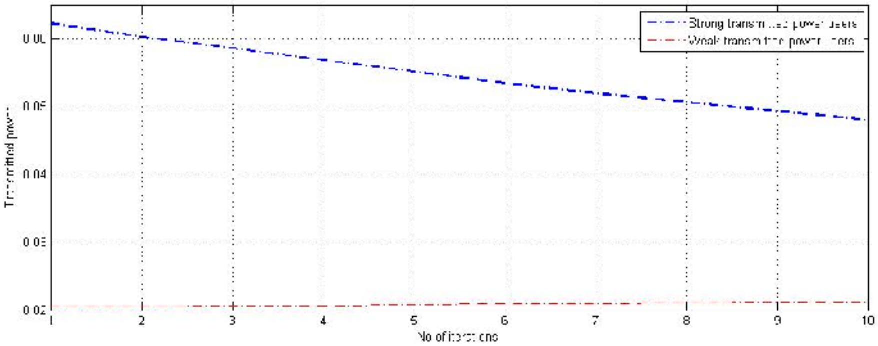


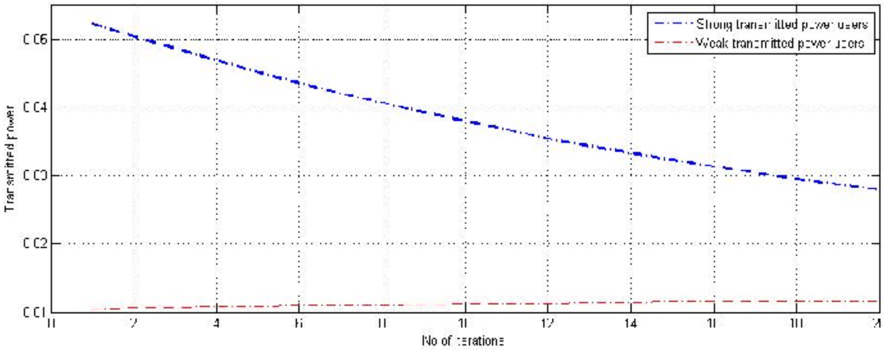
Figure 25. E_b/N_0vs. BER, desired user transmits at a power -5dB less than the other users. (Gold code, M=31, K=10).

4.2 CLPC at the Transmitter

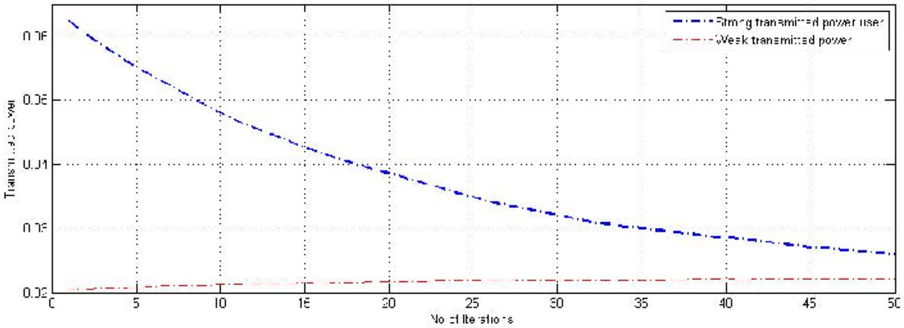
In this section, the number of iterations at CLPC to balance the transmitted powers will take into account. It is clear that, CDMA system needs an appropriate power balancer which should compensate received powers at B.S., gradually. Figure 26 shows different numbers of iterations before and after satisfactory iterations. The numbers of iterations depend on S_w which described in Chapter 3. In order to acquire an acceptable power level for all users, minimum number of iterations is proposed to be same as S_w [27]. It is obvious that with increasing number of iterations, transmitted powers of users will be equal to each other when CLPC is utilized. Here, when numbers of iterations are increased more than100, balancing the transmitted powers of either weaker users or stronger users is easier. Therefore, with increasing the number of iterations, entire users are estimated in the same power level. The simulation outcomes are shown in Figure 26. (e), (f). Simulations in this section, passing through AWGN channel are done with 10000 bits, S_w is 100 and desired Power P_d is set to 7dB.



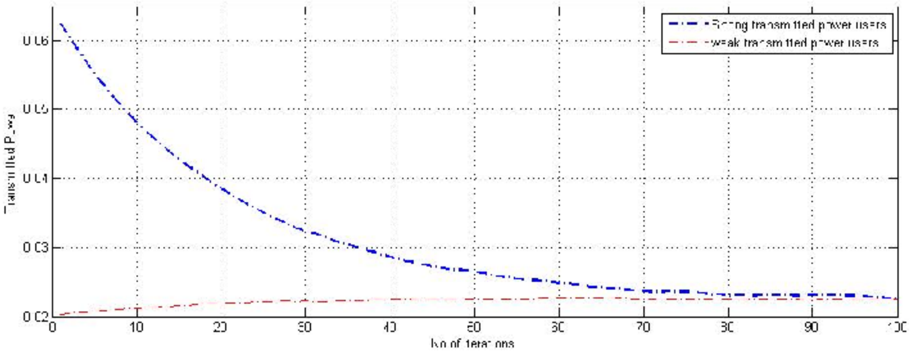
(a)



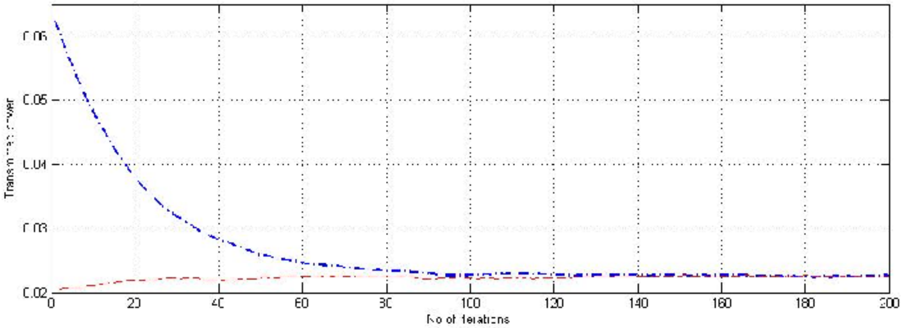
(b)



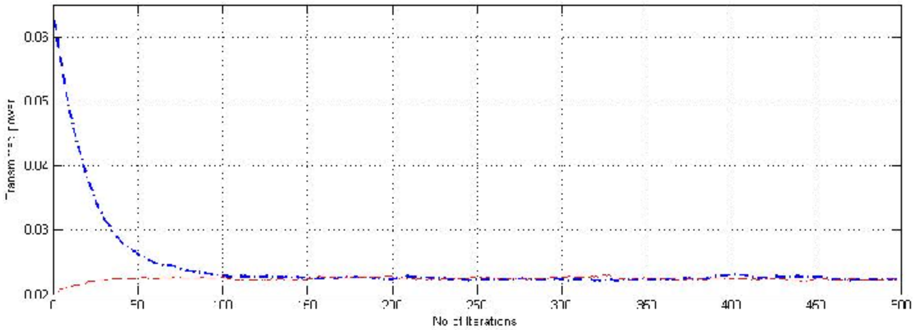
(c)



(d)



(e)

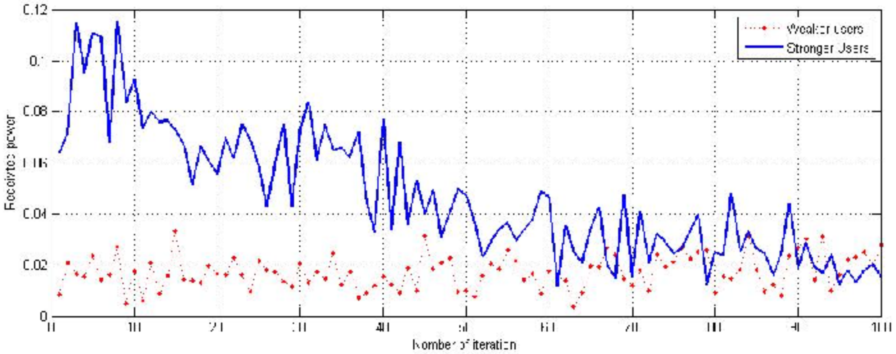


(f)

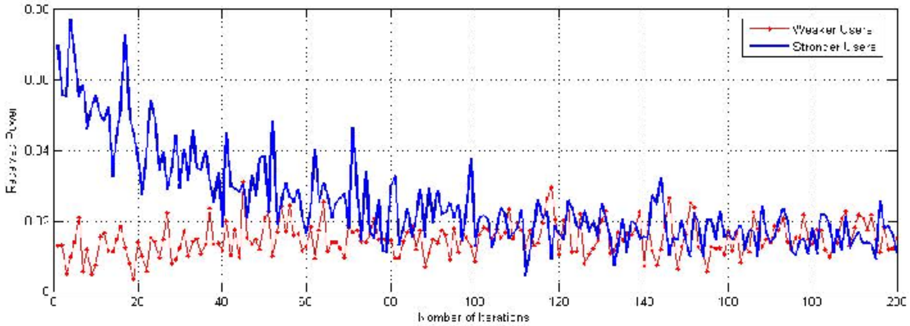
Figure 26. The effect of number of iterations in CLPC vs. Transmitted powers (a) S_w=100, No. of iterations=10 (b) =100, No. of iterations=20 (c) S_w=100, No. of iterations=50 (d) S_w=100, No. of iterations=100 (e) S_w=100, No. of iterations=200 (f) S_w=100, No. of iteration

4.3 CLPC at the Receiver

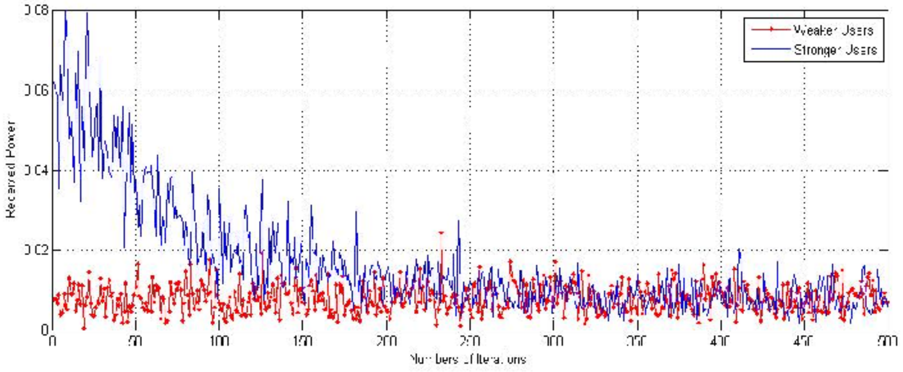
Obviously, received powers at B.S., become in an acceptable range when transmitted powers from M.S. are under the control by applying CLPC. Figure 27 illustrates the way that CLPC is going to compensate the received powers at the receiver unit. The simulation results are achieved with the same parameters as the previous section except in S_w.



(a)



(b)



(c)

Figure 27. The effect of iterations in CLPC vs. Received powers in B.S. (a) No. of iterations=100, S_w =100, (b) No. of iterations=200, S_w=100, (c) No. of iteration=500, S_w =200, (*K*=10, *M*=31, *NFR*=5, I_e =20, P_d =7, S_w =100& 200).

As seen from simulation results, there are fluctuations in received power at B.S. The effect of AWGN is the reason of such fluctuations which affects the transmitted signal from M.S. Although the effect of AWGN is considerable, power control algorithm controls effectively to compensate the received powers at an equal level.

It should be mentioned that, CLPC algorithm may influence the CDMA system much if the loop of balancing the power control becomes smaller. In other words, small and fast closed loop updating power control, leads the system faster in satisfactory conditions without missing too many transmitted bits. However, channel variations are not completely predictable and users may change their locations into the cell. For this reason, CLPC should compensate transmitted powers gradually. Hence, it is almost inapplicable to apply the extremely fast power control ones.

4.4 CLPC Applied Systems

As it can be inferred from preceding simulations, applying a power control algorithm for an acceptable CDMA system is inevitable. Here, the effect of a CLPC algorithm on a CDMA system is considered. In order for a better outstanding of the CLPC concept, two different scenarios are studied. In one scenario, half of users are in a crucial power transmission level and are -5dB weaker than the others, and in the second scenario all users transmit on the standard power level except the desired user who transmits power -5dB weaker than the other users.

4.4.1 CLPC Applied systems for Unbalanced Half of Users

In the section 4.2.1, a system was mentioned which considers the half of users with unbalance transmitted powers. Simulation results showed that, utilizing a CDMA system without an applicable power control scheme is nearly unachievable. Hence, in order to compensate the unbalance power levels an appropriate CLPC should be applied. Here, the simulation results are examined with 10000 bits for each user, 31(*M*) length Gold code used for 30 users as same as the previous simulations. Meanwhile, NFR is set to -5dB and P_d is 8dB. The simulation consequence shows clearly the effect of CLPC on CDMA system in figure 28. It should be noted that, primitive BER vs. E_b/N_0 illustration of system has rapid fluctuations in each new small change of power intervals. Therefore, for better BER determination, the average of BER’s between each E_b/N_0 unit is considered.

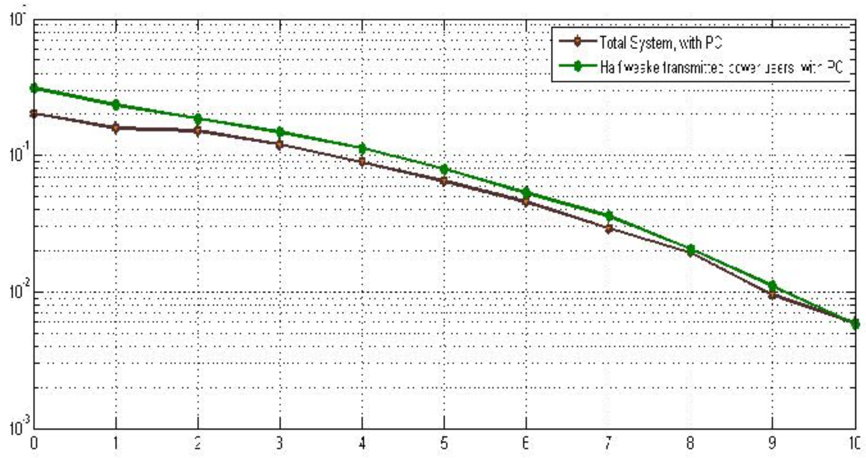


Figure 28. BER vs. E_b/N_0Unbalanced half users’ power transmission comparing to the other users in CDMA system. Half users transmit power -5dB less than the other users.

It is apparent that, after using CLPC, not only weaker users are in an acceptable power level but also the total outcome of system is in a BER which denotes a pleasant CLPC algorithm. In figure 22, at BER=10^{-1}there is a 4 dB gain in performance between weak and strong users. Although, in figure 27, at the same BER there is less than 1 dB gain in performance. This comparison is shown the effect of power control in CDMA systems.

For a better comparison between a system with CLPC and a system without CLPC, Figure 29gives a comprehensive picture. All applied data in this simulation is similar to half unbalance transmitted power level and balance transmitted power level in figures 23 and 28 respectively.

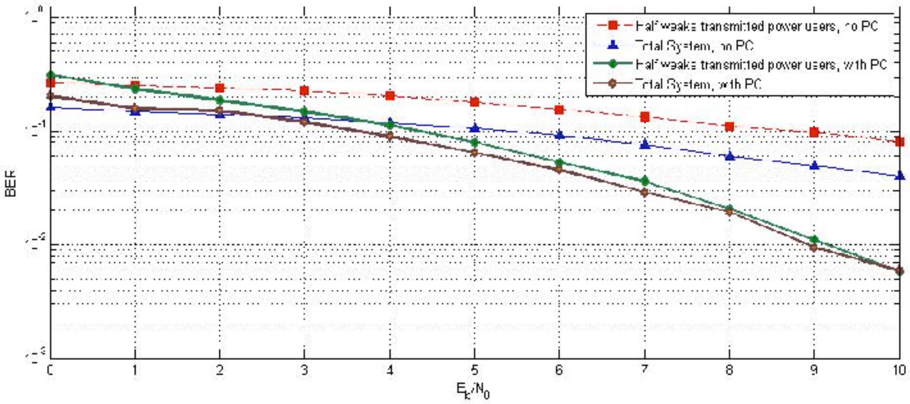


Figure 29. BER vs. E_b/N_0, half stronger and half weaker users with and without CLPC in CDMA system. (Gold code, M=31, K=30, NFR=5dB, S_w =100, P_d =8).

4.4.2 Using the CLPC for the Desired User

In the previous section, half of the users' scenario was considered under the unbalance transmitted power condition. Moreover, effect of CLPC on such a system was described. It is obvious that when a CLPC is applied, a system output becomes much better comparing with a system which does not use CLPC. The effect of CLPC on a system with the desired unbalanced power user is clarified. All users are in an acceptable transmitted power level except the desired user who transmitted at -5dB less than the other ones in the system.

Section 4.1.2 was considered a system which does not apply power control. The results of such a system showed that BER is not suitable. In this section, in order to improve the unequal power level problem, CLPC algorithm is applied. The simulation result emphasizes the necessity of applying CLPC algorithm. An experiment is done with 10000 bits for each user. Near-Far-Ratio is set to -5dB, Gold code is used for 10 users *(K)*. The target E_b/N_0 is supposed to be 7dB (P_d). In comparison to figure 24 and 29, the need of power control for each user in DS-CDMA system in is clearly seen. In figure 24, at a BER=10^{-1} the desired user performance 2.2 dB is worse than the rest of the other users. However, in figure 29, after the power control is used, at the same BER there is less than1 dB gain in performance between the desired user and the other users. Meanwhile, in figure 24, although the $E_b/N_0$is increase the performance of the desired user will not increase. But, in figure 29, it is shown that the desired user in target P_d, have the same performance as the other users. Figure 30 shows the effect of appropriate CLPC to compensate transmitted powers of users.

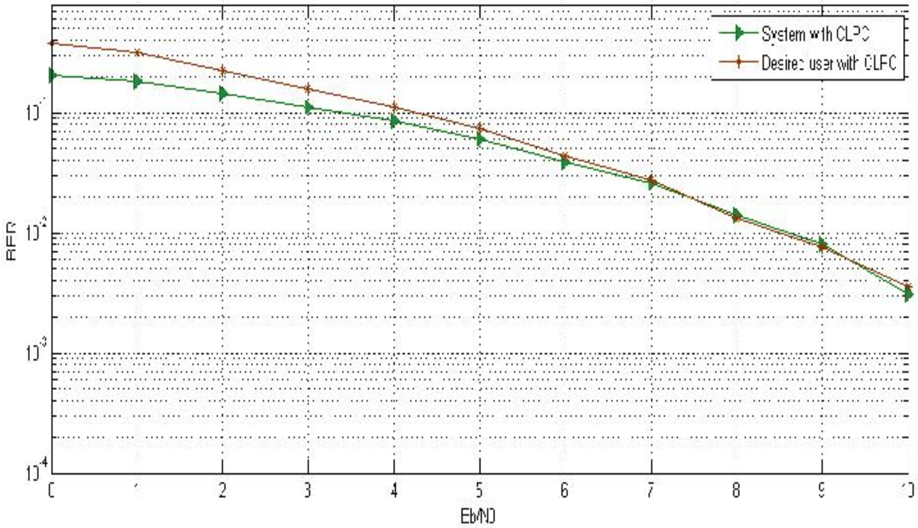


Figure 30. BER vs. E_b/N_0A desired user who is in unbalanced transmitted power situation. (Gold code, M=31, K=10, NFR=5dB, S_w=100, P_d=7).

It should be consider that the desired E_b/N_0 has been set to 7dB. However, the simulation is extended to 10dB in order to define the standard of transmitted power for higher than desired power level. It is clear from the mentioned figure that, BER of the desired user who transmitted unacceptable power level before applying CLPC converges to BER of other users after CLPC is used. Figure 31 compares BER of desired user with and without CLPC.

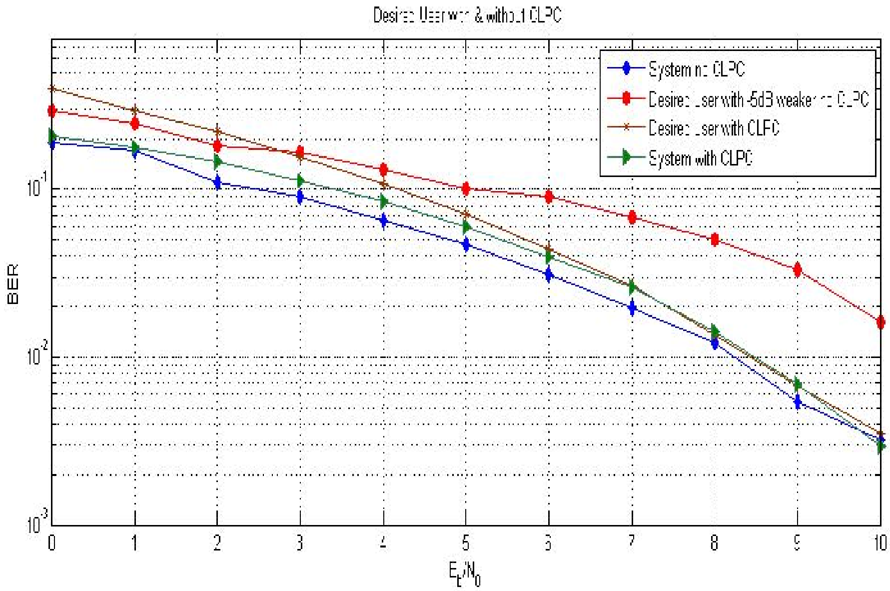


Figure 31. BER vs. E_b/N_0Comparing a system with and without CLPC to compensate unbalanced transmitted power of desired user. (Gold code, M=31, K=10, NFR=5dB, S_w=100, P_d=7).

Here, the desired $E_b/N_0$is set to 7dB. As it can be inferred from the above figure, the Bit-Error-Rate of entire users is similar to each other after using the CLPC. At last, the desired user now has an acceptable BER. It should be stated that, the BER of all users in the mentioned system do not change significantly since most of the users are in an acceptable power transmitting level. Therefore, influence of the desired user in the entire system is not crucial. However, it is important for an applicable system that all users transmit power in an acceptable level.

4.4.3 CLPC in Rayleigh Fading Channel

AWGN channel was assumed to implement through the preceding simulations. All of the parameters are the same as the previous scenarios, except the channel model. Here, multipath Rayleigh fading channel is considered in baseband. Rayleigh fading channel is based on Jakes proposed in [17]. This method briefly was explained at chapter 3.

In real world of communications, users are at different distances and within different speeds from each other and the Base Station itself. Up to now, only the effect of different distances has been considered which causes different level transmitted power problem. To modify this issue some propositions were made. Now, the speed influences of the mobile users to the system are briefly taken in to account.

In order to make a sample of Rayleigh fading, it is assumed that all users move with speed of 30Km/h on average except desired user who moves and changes its location with speed of 100Km/h. Figure 32illustrates unbalance transmitted power problem with different speed when Near-Far is 5dB. It is clear that, without any power balancer, the desired user will occur in deep fades due to rapid change of location. Meanwhile, the simulation result depict that transmitted power of mentioned user is in balanced range same as other users after CLPC is applied.

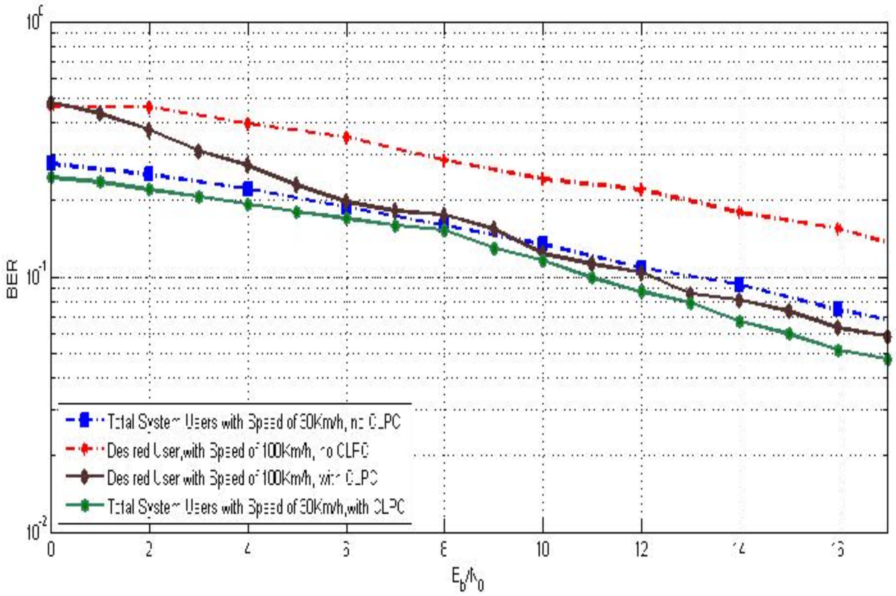


Figure 32. BER vs. E_b/N_0Comparing a system with and without CLPC to compensate unbalanced transmitted power of desired user in Rayleigh fading channel. (Gold code, M=31, K=10, NFR=5dB, S_w=100, P_d=8).

Although, the CLPC compensates the entire unbalance transmitted powers of users, the results still need additional considerations which are out of the scope of this study. For instance, due to eliminate the robust errors in Rayleigh fading channel, an appropriate interleaver should be used. It organizes transmitted signals in time slot frames. It prevents transmitted signals from changing rapidly.

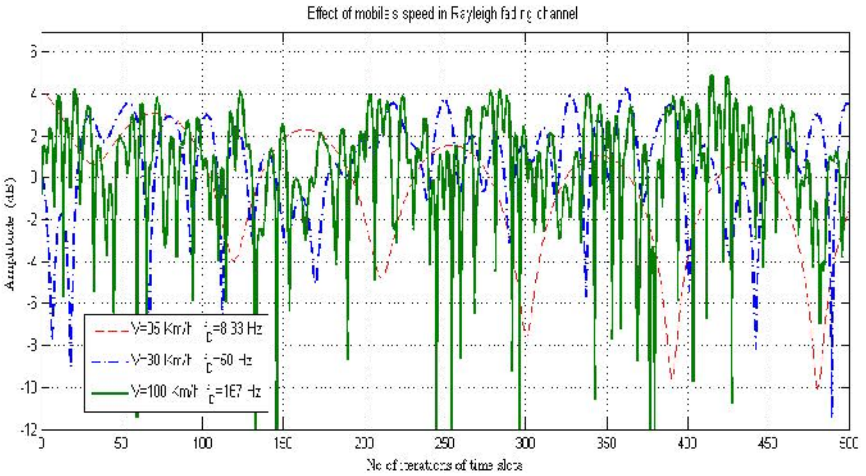


Figure 33. Comparing the amplitude of received signals vs. No. of iterations in Rayleigh Fading channel for three different speeds of mobiles. (*K*=10, Long Message=80, Long Time Slot=500, *M*=63) (based on [10]).

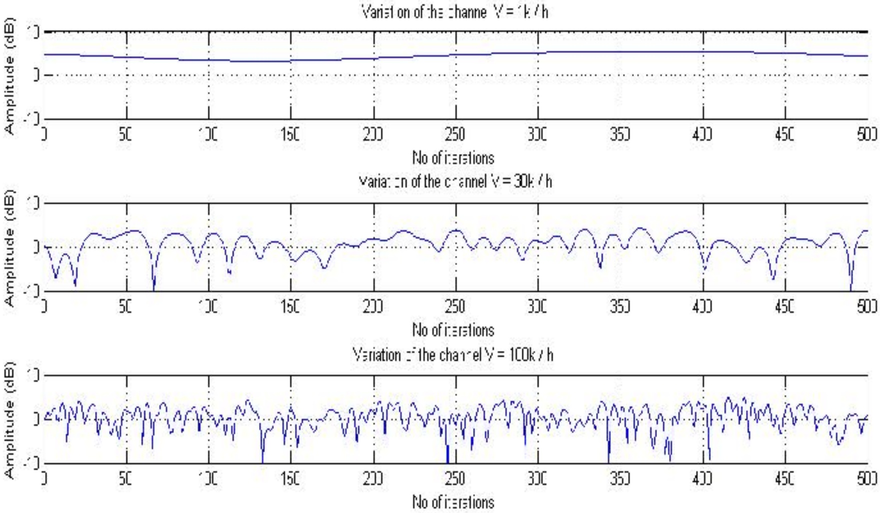


Figure 34. Amplitude of received signal vs. No. of iterations, effect of Rayleigh fading channel for three different speeds of mobiles. (*K*=10, Long Message=80, Long Time Slot=300, *M*=63).

Furthermore, it is very common that, deep fades may occur to transmitted signals when passing through Rayleigh fading channel. To resolve this, some methods such as Multi Input Multi Output (MIMO) and Rake Receivers are used to resolve the deep fades problem.

As compared to a match filter, applying more precise detectors like decorrelation detectors [28] or nonlinear detectors facilitate the detection of received signals. Figure 35 compares a simple match filter and decorrelation detector.

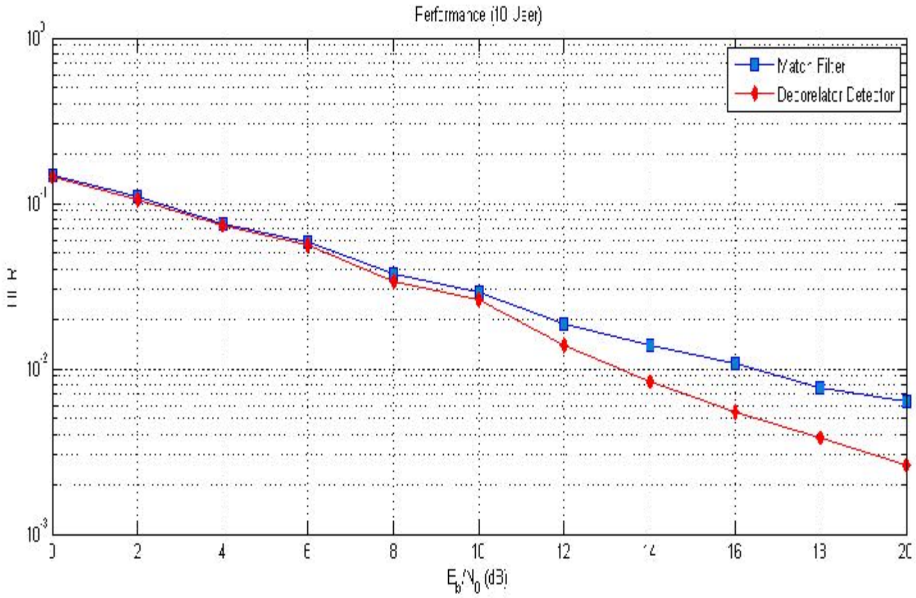


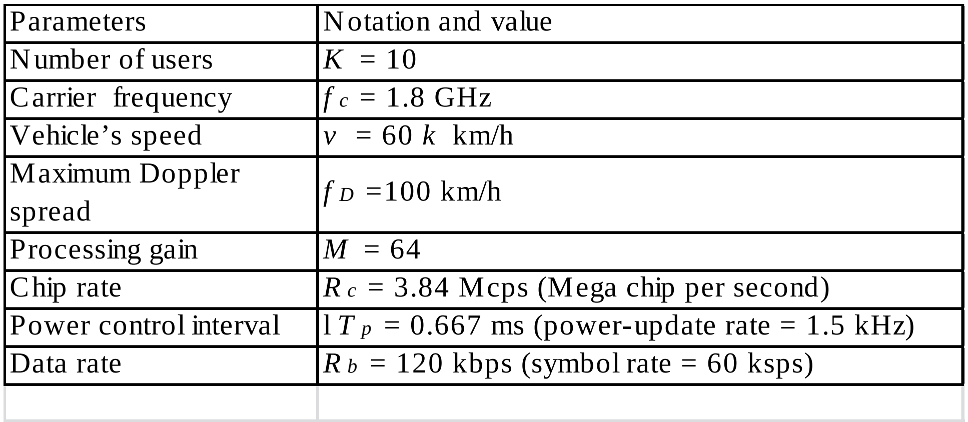
Figure 35. BER vs. E_b/N_0, compare between decorrelation detector and match filter in Rayleigh fading channel.

Simulation results in this section are based on [10]. The researcher concentrates on channelization and power control in CDMA system. From here hence, we use additional variables which initially have not been used in prior sections. Interested readers should refer to [10].

The centre frequency used in 3G is 1.8 GHz. Long messages are assumed to be of length 2560 bits with a time slot of 80 bits. The speeds of mobiles are 60 Km/h due to the carrier frequency in 3G and the Doppler frequency will be 100 Hz.

In [10], to use CLPC if the power-control –update-rate is much higher i.e. at least ten times of fading rate, CLPC becomes more effective. For clarification, it will undergo maximum Doppler frequency shifting of 100 Hz at the carrier frequency of 1.8 GHz when the mobile is travelling at 60km/h. The user power-control-update-rate has to be much greater than 1 kHz. This leads to more effective PC since the maximum Doppler spread reflects the fading rate. In 3G DS-CDMA systems, the power-control-update-rate of 1.5 kHz is being used. Received power level estimation can be applied every 0.667 ms, relating to one power control interval, or $(1/f_d)\ T_p$. A summary of the simulation parameters are shown on the table below:

Table 1. Parameters and Notations and values which used in simulation.



Parameters	Notation and value
Number of users	$K = 10$
Carrier frequency	$f_c = 1.8$ GHz
Vehicle’s speed	$v = 60\ k$ km/h
Maximum Doppler spread	$f_D = 100$ km/h
Processing gain	$M = 64$
Chip rate	$R_c = 3.84$ Mcps (Mega chip per second)
Power control interval	$1 T_p = 0.667$ ms (power-update rate = 1.5 kHz)
Data rate	$R_b = 120$ kbps (symbol rate = 60 ksps)

To illustrate fading rates influence CLPC performance, the step size is optimized for two different speeds of mobile users: 30 km/h, and 60 km/h. So as to consider the effect of fading rates, the parameter $f_D T_p$ is introduced, which shows the ratio of the fading rate to the power-updating rate. As stated earlier, the power-updating rate is standardized at 1.5 kHz so the parameter $f_D T_p$ will only be determined by the fading rate f_D, which relates to the speeds of mobile users directly. At 1.8 GHz carrier frequency, the mentioned speed corresponds to the maximum Doppler spread of 50 Hz and 100 Hz respectively. Due to a power control of T_p= 0.667 ms (rate of power updating is 1.5 kHz) and for a user moving at 30 km/h, the parameter $f_D T_p$ equals 0.033. It denotes that the mobile transmitted power is upgraded 30 times quicker than the fading rate. Moreover, for mobile speeds of 60 km/h, the parameter $f_D T_p$ is 0.067, similar to the transmitted power upgrading rates of 15 times faster than the fading rates.

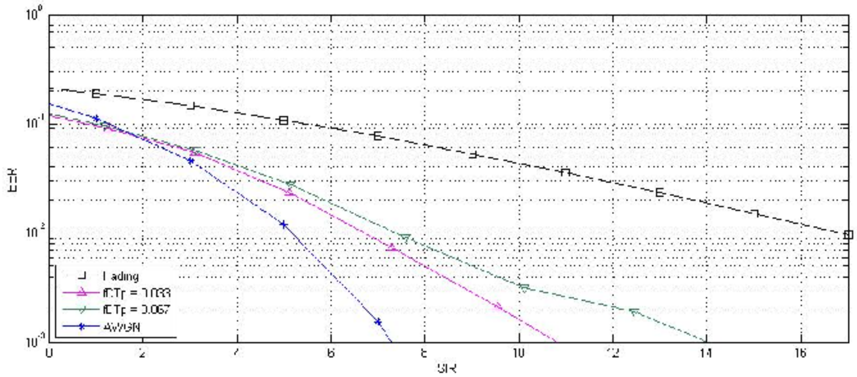


Figure 36. BER vs. SIR effect of power control update rate in Rayleigh fading channel.

Chapter 5

CONCLUSIONS AND FUTURE WORK

5.1 Conclusions

In conclusion, a DS-CDMA system is examined in AWGN and fading channels via applying Gold code and match filter multiuser detection techniques. The effect of different codes on performance of DS-CDMA system is considered. Furthermore, the performance of matched filter is compared with the decorrelation detector.

Since all users in DS-CDMA systems share the same channel, the capacity of the system is maximized, providing that transmitter's powers to be controlled. If the received power is too high, the performance of the user is acceptable. However, interference to the other users is increased and the performance of the system is degraded. Hence, the acceptable condition is that, the received power at BS is at the same level. Via applying an appropriate power control, the received signal will be at the minimum requirement. As a result, the main problems in DS-CDMA systems, i.e., Near-Far effect, Multiple Access Interference (MAI), and Signal-to-Interference (SIR) will be managed.

There are multiple types of power control. In this thesis, a Closed Loop Power Control (CLPC) based on signal strength for a synchronized DS-CDMA is proposed. The applied CLPC is easy to implement with an acceptable output. The simulation results show that, the proposed CLPC algorithm is suitable to decrease the effect of

MAI and Near-Far problems. Moreover, it can be used for AWGN and Rayleigh fading channels successfully.

In order to simulate Rayleigh fading channel, Jake’s proposed method [17] is used in two frequency bands (baseband and 3G band or 1.8 GHz).It is shown that a higher updated frequency rate, leads a better BER performance. However, increasing the updating frequency rate needs more frequency band. Thus, there is a trade-off between frequency usage and BER performance.

5.2 Future Work

The Closed Loop Power Control (CLPC) DS-CDMA in different scenarios is considered in this thesis. The CLPC DS-CDMA system can be examined in different type of channels. Also, it may be compared with other types of closed loop power control schemes like SIR-based and BER-based in order to find the optimum output.

Additionally, open loop power control (OLPC) method can be added to the system for comparison with CLPC. Moreover, in order to acquire a better BER, the system can be utilized a simple RAKE receiver. All the scenarios through this study were done for synchronous DS-CDMA systems. So, this thesis can be continued using asynchronous Ds-CDMA systems. Lastly, it may be examined for multi-cell environments with consideration of co-channel interference.

REFERENCES

[1] F. Adachi, “Wireless past and future”, the institute of Electronics, Information and Communication Engineers *(IEICE) Trans. Fundamentals*, vol. E84-A, pp.55-60, Jan. 2001.

[2] T. Ojanpera, R. Prasad, “An overview of air interface multiple access for IMT”, *IEEE Communications Magazine*, vol. 36, no. 9, pp. 82-95, September 1998.

[3] A. Karim, “On the Capacity of CDMA Systems”, Bachelor Honors Thesis II, Department of Electrical & Computer Engineering, Mac Gill University, Aprill 2002.

[4] A. Tahir, “Performance Analysis on Modulation Techniques”, M.S. Thesis, Department of Applied Signal Processing, School of Engineering, Blekinge Institute of Technology, January 2009.

[5] W. Zhon, “Simulation Environment for Software Defined Radio with Application to Wideband CDMA”, M.S. Thesis, Electronic System Design, Royal Institute of Technology, Stockholm, January 2007.

[6] C. O’Driscoll, “Performance Analysis of the Parallel Acquisition of Weak GPS Signals”, PhD. Thesis, National University of Ireland Cork, January 2007.

[7] M. K. Simon., J. K. Omura., R. A.Scholtz., *Spread Spectrum Communications Handbook*, Electronic Edition, McGraw-Hill, 2002.

[8] D. Torrieri, *Principles of Spread-Spectrum Communication Systems*, eBook, Springer, 2010.

[9] UMTS Power Control, http://wiki.hsc.com/wiki/Main/UmtsPowerControl, Retrieved on April 2011.

[10] A. Kurniawan, “Predictive Power Control in CDMA Systems”, PhD. Thesis, institute for Telecommunication Research, Division for Information Technology, February 2003.

[11] J. Choi, S. Choi, “Diversity gain for cdma systems equipped with antenna arrays” *IEEE Transactions on Vehicular Technology*, vol. 52, pp. 720 - 725, May 2003.

[12] F. Adachi, M. Sawahashi, and H. Suda, “Promising techniques to enhance radio link performance of wideband wireless access based on DS-CDMA”, *IEEE Transactions on Fundamentals*, vol. E81-A, no. 11, November 1998.

[13] R. Cameron, B. D. Woerner, “An analysis of CDMA with imperfect power control”, *IEEE Conf. Vehicular Technology*, vol.2, pp. 977 – 980, May 1992.

[14] T. S. Rappaport, *Wireless Communications*, *Principles and practice*, 2nd ed, Prentice Hall, 2002.

[15] U. Hocanin, “Closed Loop Power Control and Code Synchronization in DS-CDMA”, M.S. Thesis, Department of Electrical and Electronic Engineering, Eastern Mediterranean University, 2005.

[16] S. Salameh, “Transmit Power Control in Fixed Cellular Broadband Wireless Systems”, M.S. Thesis, Department of Systems and Computer Engineering, Carleton University, 2000.

[17] W.C. Jakes, *Microwave Mobile Communication*, New York, John Wiley, 1994.

[18] C. L. Weber, G. K. Huth, “Performance Considerations of Code Division Multiple-Access Systems”, *IEEE Transactions on Vehicular Technology*, vol. 30, no. 1, pp. 3-10, 1981.

[19] G. L. Turin, “The Effects of Multipath and Fading on the Performance of Direct-Sequence CDMA Systems”, *IEEE Transactions on Vehicular Technology*, vol. 33, no. 3, pp. 213 - 219, 1984.

[20] K. S. Gilhousen, I. M. Jacobs, R. Padovani, A. J. Viterbi., L. A. Jr. Weaver, C. E. Wheatley, "On the capacity of a cellular CDMA system", *IEEE Transactions on Vehicular Technology* , vol. 40, no. 2, pp. 303 - 312 , 1991.

[21] S. Soliman, C. Wheatley, R. Padovani, "CDMA Reverse Link Open Loop Power Control", *IEEE Conf. Global Telecommunication*, vol. 1, Orlando, FL., USA, December 1992.

[22] "Uplink power control", http://wcdma3g.blogspot.com/2008/07/uplink-power-control.html, Retrieved on March 2011.

[23] S. Ariyavisitakul, L. F. Chang, "Signal and interference statistics of a CDMA system with feedback power control", *IEEE Transactions on Communications,* vol. 41, no. 11, pp. 1626 - 1634, 1993.

[24] D. Zhang, Q.T. Zhang, C. Ko, "A Novel Joint Strength and SIR Based CDMA Reverse Link Power Control with Variable Target SIR", *IEEE Conf. International Communications*, vol. 3, pp. 1502 – 1505, 2000.

[25] D. M. Novakovic, M. L. Dukic, "Evolution of the Power Control Techniques for DS-CDMA Toward 3G wireless Communication Systems", *IEEE Communications Surveys & Tutorials,* vol. 3, pp. 2-15, 2000.

[26] A. Chockalingam, P. Dietrich, L. B. Milstein., R. R. Rao, “Performance of Closed-Loop Power Control in DS-CDMA Cellular Systems”, *IEEE Transactions on Vehicular Technology*, vol. 47, no. 3, pp. 774 - 789, 1998.

[27] N. Tekbiyik, “Closed-Loop Power Control with Fixed Step Size in DS-CDMA Cellular Systems”, M.S. Thesis, Department of Electrical and Electronic Engineering, Eastern Mediterranean University, September 2007.

[28] M. Kaleli, “Robust Successive Interference Cancellation in DS/CDMA”, M.S. Thesis, Department of Electrical and Electronic Engineering, Eastern Mediterranean University, December 2010.

[29] P. Gupta, P. R. Kumar, “The capacity of wireless networks”, *IEEE Transactions on Information Theory* , vol. 46, no. 2, pp. 388 - 404, August 2002.