Analysis of Orthogonality in CDMA Downlink

BY

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Certificate of Approval

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Abstract

In DS-spread spectrum a user signal is spread by spreading code. M-sequences are used as spreading codes. M-sequences are used in DS-spread spectrum due to their good auto correlation properties. For multiple access techniques only autocorrelation properties are not good enough, good cross correlation properties are also needed. As different m-sequence's cross correlations are not uniform and unpredictable. There is a need of a sequence having good autocorrelation and good cross correlation properties. So in CDMA a combination of Walsh and PN-sequences are used. Walsh codes are perfect orthogonal when they are synchronized. PN-sequences, Gold and Kasami sequences are used are also used in CDMA. These sequences have average autocorrelation properties and relatively good cross correlations properties. In CDMA Walsh and PN-sequences are multiplied and used as spreading codes. Walsh codes exhibit good cross correlation when these codes are aligned but when these codes lose alignment there cross correlations degraded and there is substantial orthogonal loss. In multipaths environment, signals coming from different paths have different delays so spreading codes lose there alignment and so there orthogonality. This orthogonal loss is analyzed in this paper and simulated for different mobile environments. In this analysis full Rake receiver is used. Orthogonal loss factor limits the down capacity and affects the Signal to Interference in Downlink. Orthogonal Loss factor depends upon the power delay channel profile of the multipath channel between serving base station and mobile. An expression for this factor is derived using channel power delay profile. This orthogonal loss factor values are compared with CDMA simulation results and good agreement is found. Then expression for this factor is compared with other expressions found in literature.

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Chapter 1

Introduction

Spread Spectrum Communication is in use since decades in military applications. There are two major characteristics of Spread Spectrum. First characteristic is Channel Bandwidth is much larger than required user data bandwidth. Second characteristic is Signal is randomized using a code before transmission and at receiver end this randomness is removed. On basis of randomization there are two types of Spread Spectrum Techniques. Frequency hopping spread spectrum and second is Direct Sequence Spectrum or DS Spread Spectrum. In Frequency hopping spread spectrum user signal is hopped on different frequency carriers according to a code. Receiver on the other side knows the code and sequence of hopped carriers and thus able to receive properly. So effectively signal uses a larger bandwidth. Bandwidth of spreaded Signal is secure and relatively immune to jamming. In DS Spread Spectrum user data is spread by spreading codes. Most widely used spreading codes are m-sequences. m-sequences are used due to their good autocorrelations. On transmitter side user data is spreaded by a known m-sequence and on the receiver end signal is despreaded by the same m-sequence so user data is recovered [1].

1.1 Cellular Communication

In Cellular Mobile Environment the geographical area of the system is divided in hexagonal areas called cells. Hexagonal shape is the best suited shape. In centers of adjacent hexagonal cells are equidistant. If other shapes are used like circle or square it leaves holes or adjacent centers are not equidistant. This hexagonal structure is used in planning, in real practical system cells are of irregular shapes. One cell is served by a Base Station which is usually placed at the center of the cell. In systems in which access method is Frequency Division Multiple Access (FDMA) unique set of frequencies are assigned to each adjacent cell. These frequencies can be reuse in non adjacent cells [1].

1.2 Multiple Access Techniques

There three type multiple access techniques. Each cell could have multiple frequencies. These frequencies are assigned to transceivers. A transceiver controller controls the transceivers of Base Station (BS). Fixed frequencies or pool of frequencies could be assigned to transceivers. When pool of frequencies is assigned to transceivers, slow frequency hopping could be used. Transceiver in frequency hopping mode causes less co-channel interference. And call quality also increases.

There are three widely used multiple access techniques [2].

1. Frequency Division Multiple Access(FDMA)
2. Time Division Multiple Access (TDMA)
3. Code Division Multiple Access (CDMA)

1.2.1 Frequency Division Multiple Access

In FDMA, Communication Channel is divided into sub frequency channels. Different frequency channel is assigned to each user. First Generation mobile system AMS is a FDMA system.

1.2.2 Time Division Multiple Access

In TDMA, Communication Channel is divided in time slots. Different user of system shares the same frequency at different timing. Second Generation mobile system GSM is TDMA system. In fact GSM is a TDMA as well as FDMA system. The bandwidth of GSM is sub divided into frequency channels and then each frequency is divided into time frames.

1.2.3 Code Division Multiple Access

In CDMA, Communication Channel is share by users using special codes. Each user uses whole bandwidth all the time. Each user's data is spread by a code with higher bit rate. And at the receiver the user's data is dispread by the same code. In CDMA different set of Codes are used. These spreading codes are discussed below.

1.3 Hadamard Matrix and Walsh Codes

Rows of Hadamard Matrix are Walsh codes. These codes are perfectly orthogonal that is to say if the bipolar form of code vector is multiply one to one and sum up it will give zero. Hadamard Matrices are square matrices and are generated iteratively.

Iterative equation for Hadamard matrix is below [1].

$$M_{2nx2n} = \begin{bmatrix} M_{nxn} & M_{nxn} \\ M_{nxn} & \overline{M}_{nxn} \end{bmatrix}$$

$$M_{2x2} = \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix}$$

$$M_{4x4} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 1 \\ 0 & 1 & 1 & 0 \end{bmatrix}$$

$$M_{8x8} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 1 & 0 & 0 & 1 & 1 \\ 0 & 1 & 1 & 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \\ 0 & 1 & 0 & 1 & 1 & 0 & 1 & 0 \\ 0 & 0 & 1 & 1 & 1 & 1 & 0 & 0 \\ 0 & 1 & 1 & 0 & 1 & 0 & 0 & 1 \end{bmatrix}$$

In bipolar form

$$\mathrm{R6} = \begin{bmatrix} 1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 \end{bmatrix}$$

$$\mathrm{R7} = \begin{bmatrix} 1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 \end{bmatrix}$$

$$\mathrm{R6.R7} = 0$$

1.4 CDMA based Cellular System

Code Division Multiple Access widely known as CDMA is a multiple access technique base on DS Spread Spectrum. In CDMA data of several users are transmitted simultaneously. Data of each user is spreaded by different sequence. These spreading sequences used are orthogonal to each other. In CDMA m-sequences cannot be used, m-sequences have good autocorrelation properties but have bad cross correlations properties. It is difficult to find a large set of m-sequences having good cross correlation properties [2].

In commercial CDMA standards PN-sequences and Walsh Codes are used. Walsh codes are orthogonal codes. Walsh codes are perfect orthogonal when synchronized. When unsynchronized, Walsh codes lose their orthogonal property. So when unsynchronized Walsh codes exhibits non-uniform cross correlation properties. To improve cross correlation properties Walsh codes are bit wise multiplied in polar form with PN-sequences. Walsh codes spread the signal and PN-sequences randomize and conceal the signal. Transmitter usually has a unique PN-sequence and all the users of this transmitter have this sequence in common. All users of this transmitter have a unique Walsh code. So in a vicinity of transmitters every user has unique set of PN-sequence and Walsh code [2].

On the receiver side particular PN-sequence is re multiplied with the received signal. Then signal is dispread by the users Walsh code and so the data is received. D V Sarwate and M B Pursley in their paper [1] discussed cross correlation properties of PN sequences and discussed application of PN sequences in DS-CDMA. Mo-Han Fong in her paper [3] introduced concatenated Walsh and PN sequence scheme. In this paper cross correlation properties of concatenated sequences are derived. William Stallings in his book [1] has discussed Spread Spectrum, CDMA and generation of Spreading sequences.

In commercial communication system multiple access is used. Multiple Access allows sharing of communication channels by users simultaneously. The common communication is divided in logical channels and any user has access of these channels any time. Commercial cellular uses different multiple access methods. In First Generation cellular services like AMPS Advanced Mobile Phone Service uses frequency for multiple access. This called Frequency Division Multiple Access and it is abbreviated as FDMA. With advance of digital technologies another method of multiple access become popular. It is called Time Division multiple access. It is abbreviated as TDMA. Some second Generation mobile standards use this access technique. European mobile standard which very quickly become an international standard Global System for Mobile Communications GSM uses TDMA as access method.

Each frequency channel of mobile cellular communication system is divided into time slots Ts. In GSM frame eight time slots are created. Each time slot is assigned to separate user. On the duplex channel same time slot is assigned to that user. This is the case of full rate transmission. In half rate transmission a time slot is assigned to two users which get access one by one [4].

The third recently popular multiple access technique is Code Division multiple access. It is abbreviated as CDMA. In CDMA, a code is assigned to each user. These codes are used for spreading user data. Spreaded user data uses larger bandwidth more over user data become orthogonal. So users can simultaneously transmit using same frequency and time interval. CDMA Communication systems are used in military applications since decades. The CDMA signals are secure and difficult to detect. Quite recently CDMA has been in commercial use. CDMA as commercial service launched in 1993 by Qualcom in North America [5].

1.5 Spread Spectrum Techniques

There are two well known techniques of spread spectrum. One technique is Frequency Hopping Spread Spectrum and second is Direct Sequence Spread Spectrum. In Frequency hopping spread spectrum carrier frequency is changed after specific interval of time. A pool of frequencies is assigned to transmitter and receivers. A frequency change sequence usually called hopping sequence is known to transmitter and receiver. In Frequency Hopping Spread Spectrum fast hopping is implemented that is to say frequency change occurs several times in bit duration. In second type of Spread Spectrum, Direct Sequence Spread Spectrum, spreading code is used. DS Spread spectrum is now possible due to advancement in digital technologies. Spreading codes are at higher bit rates as compared to user data. These codes are uncorrelated and in some cases completely orthogonal [6].

1.5.1 PN-sequences

Maximum length shift register sequences or m-sequences are pseudorandom sequences. Pseudorandom sequences are abbreviated as PN Sequences. Ideally autocorrelation of PN sequences have values n and 0 where n is the period of the sequence. In case of m-sequences using m number of registers, period of sequence is $n = 2^m - 1$. 1. In ideal random sequence values of autocorrelations are 1 and 0. Whereas in PN-sequences autocorrelations are 1, -1/n which are almost ideal for large n. Cross correlations of m-sequences have high peaks which is not wanted. So we need such sequences which have autocorrelation like m-sequences and cross correlations better than m-sequences [7].

For CDMA two sequences could be used, widely known as Gold and Kasami sequences. Pseudo Noise Sequences abbreviated as PN-sequences are random sequences. These sequences are binary series of 0,s and 1,s. These sequences are almost look like random. PN Sequences are very close to randomness so these sequences can be used to separate user data on same frequency. When spreaded by these sequences user data just look like random noise and it is very difficult to detect. Only real receiver knows the sequence and it can despread and recover the data [7].

Binary PN-Sequences are generated using Binary polynomials implemented through shift registers. A shift register sequence of m size produces a sequence of length 2^m-1. So m-shift registers produces a sequence having period 2^m-1. PN sequences have some specific properties. The symbols of these sequences are equally probable. Auto correlation of these sequences has two values n and -1, where n is the period of the sequence. It is impossible to predict next bit after observing less than n bits. If n bits are observed the sequence is no more random it is deterministic [7].

Second Generation Cellular Code Division Multiple Access CDMA standard uses two codes. One code is used for spreading and other is used for scrambling. One Channel's bandwidth is 1.25 MHz. Users are spreaded on the forward links and after synchronization. On uplink, instead spreading user data, data is coded in orthogonal codes and then these codes are spreaded through PN Sequences. PN-sequences of two different orders are used in Cellular CDMA standards. The codes are named as Short codes and Long Codes [8]. The short description of these codes according to commercial CDMA is as follows.

1.5.2 Short PN Code:

Short PN Code is 2^{15}-1. It is implemented through fifteen stage shift registers. Length of the code is measured in chips. One chip corresponds to one bit. Chip rata of Short PN Code is 1.2288 M chips per second. So code has a time period of 26.67ms. As autocorrelation of shift versions of these PN sequences are almost zero so shift versions can be used. 32768 shifts are available for short PN code. In multipath lag of one code looks like the other code. So to be safer side 64 chip distant codes are used. This makes 512 available short codes. Short codes are used in Forward link to identify Base Station and Sectors. Short cord of BS is always unique with adjacent BS. In commercial network code planning is done very carefully otherwise a BS having same code as adjacent BS will experience severe interference [8].

1.5.3 Long PN Code:

Second Code which is used in CDMA systems is Long PN-Sequence long code. Use of this code is different in Forward link and Reverse Link. Long PN Scrambling has order 42. It is implemented through forty two stages of shift register. So period of this code is 2^{42}-1. At chip rate of 1.2288 MHz time period of sequence is 35.79 10^{6}sec. In Third Generation CDMA system 42 stage shift register is not used instead two PN sequences of 25 order are used Segments of these sequences are modulo two added and so long sequence is generated [8]. In case of Long sequence of Order 42, 2^{42}-1 shift of this code can be used due to good auto correlation properties. As in multipath environment a code sequence in lag resembles the other code. Only subset of shifted versions of the code is used. It is in practice that code separated by 512 chips should be used. It makes 2^{23} available codes [6]. In Forward Link Long PN Sequences are used as scrambling codes and are used in access channels and paging channels. In Reverse link these long PN Sequence codes are used for to identify a mobile. To each mobile user a unique long code is assigned and its used for spreading in reverse link.

1.5.4 Code Synchronization

Codes are known to transmitter and receiver before hand. But these codes are not synchronized all the time. Special procedures are adopted to synchronize these codes. This process is divided into two processes Acquisition and Tracking. In acquisition process sliding correlators are used. When output of the correlator reaches a certain threshold it shows code is acquired. So it is time for fine time synchronization and tracking. Special PLL devices are used for tracking and synchronization. Fine chip synchronization and phase tracking is done for coherent detection [7].

1.5. 6 CDMA Logical Channels

In CDMA Forward link 64 codes are available. These codes are used as logical channels. Some channels are used as signaling control channels and some are used as traffic channels. These codes are used for spreading. Then scrambled by Long and short codes. Then it is modulated. In Forward link QPSK modulation is used. Logical channels details are given below [6].

1.5.6.1 Pilot channel

It is forward link logical channel. Pilot is the main and unique channel of the BS. BS is identified with its pilot channel. It is used for power measurement during handovers. Walsh code W0 is used for pilot channel and it is all binary zeros. Pilot data rates are 4.8 and 9.6kbs.

1.5.6.2 Synchronization Channel

Walsh code W32 is used for synchronization channel. It is forward link logical channel. Pilot and Synchronization channel are combined used for tracking. It gives state of long Code.

1.5.6.3 Paging channel

Paging channels are Forward link logical channel. Seven Paging are assigned to one BS. Walsh codes W1 to W7 are used. All signaling and control commands are carried by paging channels. Typical paging messages include System Parameter message, Adjacent Neighbors list message, Channel list message and mobile list message. Authentication is also done on this channel.

1.5.6.4 Access Channel

Access Channel is reverse link channel. It is used with paging channel which is on forward link. Three types of messages are carried by access channel. These are Call request message, response to paging message and location updating message.

1.5.7 Forward Traffic Channels:

Forward traffic channels carry user voice call and user data. Walsh channels W8 to W31 are used for forward channels. The traffic channels of a BS transmitted in synchronized and aligned fashion. So the data channels are completely orthogonal at the time of transmission. The user data is speech code then it is channel coded then it interleaved then spreaded by forward traffic channel codes then it multiplied by short code then it is scrambled by long code. If a BS is working on full capacity then interference level will be high. CDMA is interference limited system. Interference is caused by other users. So if few users are present interference will be less.

1.5.8 Reverse Link

On reverse link large numbers of logical channels are available, about 2^{33}, 8.5 billion logical channels in a network. On reverse link Walsh codes are not used for spreading. Walsh codes are used for code modulation. 64 Walsh codes are available. 6 bits of user data are mapped to unique Walsh code then this code is spreaded by long PN-sequence code.

1.5.9 Handoff

Handoff is a process in which a active mobile station move from one Base station to other base station. Active user is that user whose call is in progress. MS and BS continuously monitors power level of the signal. When signal power level drops from certain threshold handoff process is initiated. There are two types of handover hard and soft [4].

1.5.9.1 Soft Hand over

Soft Handover is process in which mobile station handover adjacent Base Station on the same frequency. This Soft handover is unique to CDMA cellular system. When handover started MS clamps to adjacent BS having highest signal power and connection with the previous BS is still there. When connection with new BS is stable, connection with previous BS is dropped.

1.5.9.2 Hard handover

In hard handover operating frequency is changed. In this case on adjacent BS required frequency is not available so a new frequency is assigned. So frequency change message is sent to MS by BS. So MS performs handover to different frequency Base Station. In FDMA system Hard handover is typical hand over where as soft hand over is not possible because adjacent Base stations always have different frequencies.

Chapter 2

Correlations and Orthogonality in CDMA

Comparison of sequences is called correlation. It is a measure of similarity between two sequences. Correlation of two sequences depends on length and phase of sequences. In case of discrete sequences symbol length also take part. There are two types of correlations one is called auto correlation the other one is called cross correlation. In auto correlation sequence is correlated with itself. Auto correlation is measure of similarity of sequence in different phases. In correlation process one sequence is slide past the other sequence and comparisons are made. Number of agreements minus number of disagreement is equal to correlation. In case of periodic sequences higher correlations occur periodically [9].

To find auto correlation of a square wave, a replica of the wave is created. Then replica wave is slid over the original wave. Numbers of differences are counted and numbers of agreements are counted. Differences are subtracted from agreements result is noted for the delay in the wave. The process is repeated for several values of delays and corresponding correlation values are noted. Then the correlation values are plotted against delays which gives a triangular wave form. The peak shows perfect match and lowest point shows that waves are 180 degrees out of phase. Mathematically this can be done by multiplying two wave form with different delays and apply summation in case of discrete waves and integrate in case of continuous waves. In case of zero delay the auto correlation value is equal to power of the signal.

$$C(\tau) = \int s(t)q(t+\tau)dt \tag{2.1}$$

Passerini and Falciasecca simulated and modeled the orthogonality factor in urban environment. Forward link quality is greatly affected by orthogonality factor.

Investigation were made for correlation between orthogonality factor Root mean square delay spread in microcellular environment. 3G mobile systems uses code division multiple access for spectrum reuse. 3G provides multimedia services in which data rates vary from 8kbit/s to 2Mbit/s. In these multimedia application traffic on forward link and reverse link are not equal. User request downloads using few bytes and heavy forward link traffic starts in response [10].

Investigation were made for a factor affecting the performance of the forward link and it is named as orthogonality factor. In CDMA forward link orthogonal codes are used to spread data form base station to user mobile station. The users are separated by these orthogonal codes. An orthogonal code is assigned to each user. Reflection and scattering in multipaths environment affects the synchronization of the codes due to which orthogonality of codes decreases which creates inter user interference among users of the same Base Station. Multipaths produce interference between the bits of users.The expression of OLF is derived assuming that the external interference and noise are absent. Given an F-finger rake receiver operating a maximal ratio combining the following relation holds.

$$(OLF)^{-1} = \sum_{f=1}^{F} \frac{|\beta_f|^2}{\sum_{j\neq f} |\beta_j|^2} \tag{2.2}$$

where it is assumed that the rake receiver is capable of sorting echoes amplitudes $|\beta_j|$ in decreasing order and extracting power from the first F relevant echoes [10].

Mo Han Fong investigated the application of the concatenated orthogonal/PN spreading scheme for a cellular direct sequence code division multiple access (DS-CDMA) system with integrated traffic. The performance of the system is evaluated in terms of user capacity. In order to incorporate traffic with a wide range of source rates, line rates (adjusted data rates before spreading) have to be selected for transmission. For traffic with source rates higher than the line rate of concern, she proposes the use of concatenated orthogonal/PN spreading sequences. The results are used to evaluate their performance for homogeneous voice traffic in various cellular mobile environments with multipath fading, lognormal shadowing, and path loss. Their results show that the proposed spreading scheme offers a significant improvement in forward link capacity as compared to using the conventional non concatenated long PN sequence, especially if the multipath fading is Rician (e.g., microcellular and indoor Pico cellular systems). Incorporating the notion of line rate, we then evaluate the performance of a system with integrated voice and video traffic. Special emphasis is placed on the effect of line rate selection on the overall capacity which leads to the optimal selection of line rates [3].

Lindholm, J derived expressions for the moments of the distribution of weights of m-tuples or subsequences of long m-sequences. The expressions display a systematic relationship between the moments and the characteristic polynomial or generating function. An algorithm for determining the third moment, which measures skew ness, is shown to provide a practical aid for selecting optimum m-sequences for various correlation-detection design problems [11].

Sarwate and Pursley worked on cross correlation properties of pseudorandom and related sequences.Binary maximal-length linear feedback shift register sequences (m-sequences) have been successfully employed in communications, navigation, and related systems over the past several years. For the early applications, m-sequences were used primarily because of their excellent periodic autocorrelation properties. For many of the recent systems applications, however, the cross correlation properties of such sequences are at least as important as the autocorrelation properties, and the system performance depends upon the aperiodic correlation in addition to the periodic correlation. This paper presents a survey of recent results and provides several new results on the periodic and aperiodic cross correlation functions for pairs of m-sequences and for pairs of related (but not maximal-length) binary shift register sequences. Also included are several recent results on correlation for complex-valued sequences as well as identities relating the cross correlation functions to autocorrelation functions. Examples of problems in spread-spectrum communications are employed to motivate the choice of correlation parameters that are considered in their paper [2].

Sarwate and Pursley discussed Partial Correlation Effects in Direct-Sequence Spread-Spectrum Multiple-Access Communication Systems in their paper. Nearly all previous analytical results on the performance of direct-sequence spread-spectrum multiple-access (DS/SSMA) communication systems are restricted to systems in which the period p of the signature sequence is equal to the number N of chips per data symbol. In many applications, however, it is necessary to employ signature sequences whose period p is much larger than N. Thus, successive N-chip segments of the signature sequence are used to phase-code the carrier during the transmission of successive data symbols. The performance of such systems depends on the partial correlation properties of the signature sequences (rather than the aperiodic correlation properties as in the case when N = p). In this paper, we consider the performance of a DS/SSMA system for arbitrary values of p and N. As special cases of our results, we determine the effects of partial correlation in three classes of systems: those for which N = p, those for which N and p are relatively prime, and those for which N is a divisor of p. e also provide two methods for the design of sequences for systems for which N is a divisor of *p* [12].

Chapter 3

Formulation of Orthogonal Loss

Each user in CDMA is assigned a pair of Walsh Code and PN-sequence. In DS-CDMA standards, one transmitter have one PN-sequence and 64 to 128 Walsh codes. CDMA is interference-limited system; all users share the same bandwidth, increasing number of user increases the interference. The loss of synchronization between users also increases the interference. In Cellular mobiles base station transmits synchronized users data after spreading it by concatenated codes. Due to presence of multipaths in the mobile environment the signals of the users of same transmitter do not remain synchronized and loss the alignment at the receiver. This loss of alignment of users with each other results in orthogonal loss in user's signals. So these users start to cause interference to other users of the same transmitter.

In CDMA mostly widely type of receive in used is Rake receiver. This is receiver is called Rake its structure similarity with rake tool. Rake receiver has fingers. The received signal is passed through these fingers. Every finger has a constant called finger weight *f*. The finger weights are adjusted according to the channels condition and attenuation constants *p*. The transmitted signal is attenuated through path constants *p*. Then it passes through the rake receiver finger and multiplied with the finger weight *f*. The finger weight *f* is adjusted so that it minimizes the signal error. One way to optimize the rake receiver weight is to set it equal to path attenuation *p*.

3.1 Signal to User Interference Ratio SIR

The transmitted CDMA signal is received at the input of the Rake receiver. The received signal passed through Rake finger and multiplied by finger weights. Finger weights correspond to attenuation in that signal path. The Signal to User Interference ratio at the output of the Rake receiver of User can be written as [13]

$$\frac{S}{I} = \frac{M S_u (\sum_{n=1}^{N_F} f_n p_n)^2}{O.S_T \sum_{n=1}^{N_N} (p)^2 \sum_{n=1}^{N_F} (f)^2 - O.Su. \sum_{n=1}^{N_N} (p)^2 \sum_{n=1}^{N_F} (f)^2} \tag{3.1}$$

Su is Signal power of User, S_T is Transmit Signal Power of all users, M is Spreading factor, p is instantaneous attenuation of multipath, O is Orthogonal Loss Factor and f is weights of Rake receiver. In (3.1) Numerator is power of the signal at the output of the rake receiver. It is the weighted combination of signal from all rake fingers. Denominator is interference of other user at the output of rake receiver. In O, Orthogonal loss gets define as

$$O = \frac{S_u I_o (\sum_{n=1}^{N_F} p_n f_n)^2 M}{S_T S^{(i)} \sum_{n=1}^{N_N} (p_n)^2 \sum_{i\ n=1}^{N_F} (f_n)^2 - S_u S^{(i)} \sum_{n=1}^{N_N} (p_n)^2 \sum_{i\ n=1}^{N_F} (f_n)^2} \tag{3.2}$$

In CDMA downlink a bipolar symbol stream is spread by a Walsh codes and then multiplied by PN sequences. The Walsh increase the bandwidth of the signal and these codes make the user signals orthogonal. The PN-sequence randomizes the signal. The signals of different users are synchronized So that the codes are orthogonal at the transmitter. PN sequence is shared by the all users of the transmitter. Every user have a different Walsh code. If there are other transmitters they will have different PN-sequence but same set of Walsh codes. The user signal transmitted is given by

$$s(t) = \sum_{u=0}^{U} \frac{\sqrt{S_u}}{2} m^{(u)}(t) c^{(u)}(\mathrm{t}) \tag{3.3}$$

Total number of users transmitted by the transmitter U and m are the bipolar bits of the user data and c is the spreading codes and S_u is the transmit power of the user signal.

Orthogonal loss can be evaluated using by calculating the Signal Power(S) and Users collective interference power I at the output of the rake receiver. The signal of is received by the rake and passed through the fingers of the rake. Every finger processes signal of the particular path and match its time delay then uses this delay to despread and correlate with correct sequence. Using Correlation properties define in [3] we can express UI, the User signal at the output of rake receiver , which causing interference as

$$UI^{(u)} = \frac{\sqrt{S_u}}{2} \sum_{n=1}^{N_F} \sum_{\substack{l=1 \\ (l \neq n)}}^{N_T} p_l f_n \times [m_{-1}^{u} \Re_{0,m}(x, \tau_l - \tau_n) + m_0^{(u)} \widehat{\Re}_{0,u}(x, \tau_l - \tau_n)] \tag{3.4}$$

Where $\Re_{0,u}$ and $\hat{\Re}_{0,u}$ are correlations of spreading codes of 0th and uth user. $\Re_{0,u}$ is the correlation of code from 0 to x time interval and $\hat{\Re}_{0,u}$ is the correlation of code from x to Ts. Ts is a symbol duration. m_o and m_{-1} are users 0th and -1th bit which is in fact in delay and causing interference to 0th bit. $\Re_{0,u}$, $\hat{\Re}_{0,u}$ and $m^{(u)}$ are defined as under

$$\Re_{0,u}(x, \tau) = \int_0^x c^{(0)}(t + xT_c - \tau) c^{(u)}(t + xT_c) dt \tag{3.5}$$

$$\hat{\Re}_{0,u}(x, \tau) = \int_x^{Ts} c^{(0)}(t + xT_c - \tau) c^{(u)}(t + xT_c) dt \tag{3.6}$$

$$m^{(u)} = \begin{cases} m_{-1}^{(u)} & -T_s \leq \tau < 0 \\ m_0^{(u)} & 0 \leq \tau < T_s \end{cases} \tag{3.7}$$

The signal of intended user after passing through rake and after dispreading can be expressed as where M is the spreading gain and m is bit transmitted

$$S^{(0)} = \sqrt{S_u} M m_0^{(0)} \sum_{n=1}^{N_F} p_n f_n \tag{3.8}$$

$$\left| S^{(0)} \right|^2 = M^2 Su \ (\sum_{n=1}^{N_F} p_n f_n)^2 \tag{3.9}$$

The only interference which is considered here is User Interference UI at the output of Rake receiver. Other interferences as adjacent cell interference and white noise are negligible. The total interference power at the output of the rake receiver after taking expectation over all spreading codes is equal to Io.

$$I_o = E\left[\sum_{u=1}^{U} UI^{(u)^2} \right] \tag{3.10}$$

Using value of UI from expression (3.4) and placing it in expression (3.10), value of Io is

$$E\left[UI^{(u)^2} \right] = \frac{P_u}{4} \sum_{n1=1}^{N_F} \sum_{\substack{l1=1 \\ l1 \neq n1}}^{N_T} \sum_{n2=1}^{N_F} \sum_{\substack{l2=1 \\ l2 \neq n2}}^{N_T} p_{l1} f_{n1} p_{l2} f_{n2} \tag{3.11}$$

$$\times E\left[\ [b_{-1}^{u} \Re_{0,u}(x, \tau_{l1} - \tau_{n1}) + b_0^{(u)} \widehat{\Re}_{0,u}(x, \tau_{l1} - \tau_{n1})][b_{-1}^{u} \Re_{0,u}(x, \tau_{l2} - \tau_{n2}) + b_0^{(u)} \widehat{\Re}_{0,k}(x, \tau_{l2} - \tau_{n2})] \ \right]$$

Correlation expressions of codes under expectation on the right side of the equation can be simplified. Factors under expectation are multiplied. Now the product terms having b_0b_{-1} become zero as expectation $E(b_0b_{-1})$ is zero. The transmitted symbol b is bipolar and equally probable so there expectation is zero. The expression (3.11) simplified to (3.12)

$$E\left[UI^{(u)^2}\right]=\frac{P_u}{4}\sum_{n1=1}^{N_F}\sum_{\substack{l1=1\\ l1\neq n1}}^{N_T}\sum_{n2=1}^{N_F}\sum_{\substack{l2=1\\ l2\neq n2}}^{N_T}p_{l1}f_{n1}p_{l2}f_{n2} \tag{3.12}$$

$$\times\left[\ E_x[\Re_{0,u}(x,\tau_{l1}-\tau_{n1})\Re_{0,u}(x,\tau_{l2}-\tau_{n2})]+E_x[\hat{\Re}_{0,u}(x,\tau_{l1}-\tau_{n1})\hat{\Re}_{0,u}(x,\tau_{l2}-\tau_{n2})]\ \right]$$

$\Re_{0,u}$ and $\hat{\Re}_{0,u}$ are correlation expressions in continuous domain. These expressions are derived by Fong [3] can be expressed in discrete time as (3.13) and(3.14) .

$$\Re_{0,u}(x,\tau)=C(c^{(0)}_{(x-M)},c^{(u)}_{(x)})(l-M) \tag{3.13}$$

$$\hat{\Re}_{0,u}(x,\tau)=C(c^{(0)}_{(x)},c^{(u)}_{(x)})(l) \tag{3.14}$$

where $l=\lfloor \tau/T_c \rfloor$ and

$$C(c^{(u)}_x,c^{i}_y)(l)=\begin{cases}\displaystyle\sum_{j=0}^{M-l-1}c^{(u)}_{x+j}c^{(i)}_{y+j+l} & 0\leq l<M\\ \displaystyle\sum_{j=0}^{M+l-1}c^{(u)}_{x+j-l}c^{(i)}_{y+j} & -(M-1)\leq l<0\end{cases} \tag{3.15}$$

$C(c^{(u)}_x,c^{(i)}_y)(l)$ is discrete time correlation of concatenated codes and c_x is the code of u^{th} user and c_y is the code of i^{th} user and l is separation delay in the codes. Using discrete time correlation in (3.12) it becomes (3.16)

$$E\left[UI^{(u)^2}\right]=\frac{P_u}{4}\sum_{n1=1}^{N_F}\sum_{\substack{l1=1\\ l1\neq n1}}^{N_T}\sum_{n2=1}^{N_F}\sum_{\substack{l2=1\\ l2\neq n2}}^{N_T}p_{l1}f_{n1}p_{l2}f_{n2} \tag{3.16}$$

$$\times\left[\ E_x[C(c^{(0)}_{(x-M)}c^{(m)}_x)(l_1-M)C(c^{(0)}_{(x-M)},c^{(m)}_x)(l_2-M)]+E_x[C(c^{(0)}_{(x)},c^{(m)}_x)(l_1)C(c^{(0)}_{(x)},c^{(m)}_x)(l_2)]\ \right]$$

The following properties of Walsh codes and PN sequences are useful. These properties are derived in the paper by Fong [3].

$$E_x[C^2(c^{(0)}_{(x-M)}c^{(u)}_x)(l-M)]+E_x[C^2(c^{(0)}_{(x)},c^{(u)}_x)(l)]\approx 2M \tag{3.17}$$

$$E_x[C(c^{(0)}_{(x-M)}c^{(u)}_x)(l-M)C(c^{(0)}_{(x-M)}c^{(u)}_x)(l+j-M)]\approx 0, \qquad (j\neq 0) \tag{3.18}$$

$$E_x[C(c^{(0)}_{(x)},c^{(u)}_x)(l)C(c^{(0)}_{(x)},c^{(u)}_x)(l+j)]\approx 0, \qquad (j\neq 0) \tag{3.19}$$

Using Discrete time properties of codes (3.17), (3.18) and (3.19) in equation (3.16) we get expression (3.20).

$$E\left[UI^{(u)^2}\right]=\frac{(S_u-P_o)M}{2}\sum_{n1=1}^{N_F}\sum_{\substack{l1=1\\ l1\neq n1}}^{N_T}\sum_{n2=1}^{N_F}\sum_{\substack{l2=1\\ l2\neq n2}}^{N_T}p_{l1}f_{n1}p_{l2}f_{n2} \quad \text{where } l_1-n_1=l_2-n_2 \tag{3.20}$$

$$I_o=E\left[UI^{(u)^2}\right]=\frac{(S_u-P_o)M}{2}\sum_{n1=1}^{N_F}\sum_{\substack{l1=1\\ l1\neq n1}}^{N_T}\sum_{n2=1}^{N_F}\sum_{\substack{l2=1\\ l2\neq n2}}^{N_T}p_{l1}f_{n1}p_{l2}f_{n2} \quad \text{where } l_1-n_1=l_2-n_2 \tag{3.21}$$

3.2 Orthogonal Loss Formula

From(3.2), (3.3) and(3.21), we get the final expression of Orthogonal Loss factor(3.22).

$$O=\frac{\sum_{n1=1}^{N_F}\sum_{\substack{l1=1\\ l1\neq n1}}^{N_T}\sum_{n2=1}^{N_F}\sum_{\substack{l2=1\\ l2\neq n2}}^{N_T}p_{l1}f_{n1}p_{l2}f_{n2}}{(\sum_{l=1}^{N_T}(p_l)^2)(\sum_{n=1}^{N_F}(f_n)^2)} \quad \text{where } l_1-n_1=l_2-n_2 \tag{3.22}$$

The expression contains multi path attenuation and weights factor of rake receiver. It also depends on number of multi paths and number of fingers of Rake receiver. It does not depend on the user data or correlation properties of concatenated codes. At least correlation properties of concatenated sequences used in this analysis have any effect in final expression. Another important aspect of this expression is that of relation between multipath and rake fingers delay. Only those pair multipaths and rake fingers interfere with each other which have equal time delay.

Chapter 4

Results and Discussions

Orthogonal loss is plotted on time line for different channel conditions. Multipath channel conditions which are used are Rural Area Channel, Hilly Area Channel and Urban Area Channel. The different mobile environment where used in simulation. Rural area is vast last land with less building and obstacles. It has multipaths delay of 5us. Urban Area with lot of building structure and lot of multipaths having power profile delays of 20us. And Hilly area with multipaths delays of 20us and also have a cluster of multipaths having delay 15 us and having significant power. The analysis expression (3.22) of Orthogonal Loss Factor OLF contains multi path attenuation and weights factor of rake receiver. It also depends on number of multi paths and number of fingers of Rake receiver. It does not depend on the user data or correlation properties of concatenated codes. At least correlation properties of concatenated sequences used in this analysis have no effect in final expression. Another important aspect of this OLF expression is that of relation between multipath and rake fingers delay, only those pairs of multipaths and rake fingers interfere with each other which have equal time delay.

Scrambling code, 32 chip long Gold sequence of Order 5 is used. Walsh code of length 4 is multiplied with Gold sequence. There are three Walsh code so three users are used in the simulations a unique code is assign to each user. Orthogonal loss expression (3.2) (3.2) is used for simulation and expression (3.22) is used and for analysis. Orthogonal loss values are plotted in Figure 1 using expressions (3.2) and (3.22). Comparisons of Statistics of Orthogonal loss are as follows. Time traces of Orthogonal loss using Rural

Area Channel Profile. Results of simulation and analysis are ploted. A good match in simulation and analysis is observed. For Rural Area profile, values of Orthogonal loss are very low. Simulation, dotted graph is a plot of Equation (3.2) in this equation instantaneous values of Interference Power I and Signal power S are used. Analysis, solid graph is a plot of orthogonal loss Formula (3.22). In this formula only instantaneous channel parameters are needed. Simulation and Analysis are perfectly matched. So Orthogonal Loss Formula can be used for further study of CDMA orthogonality.

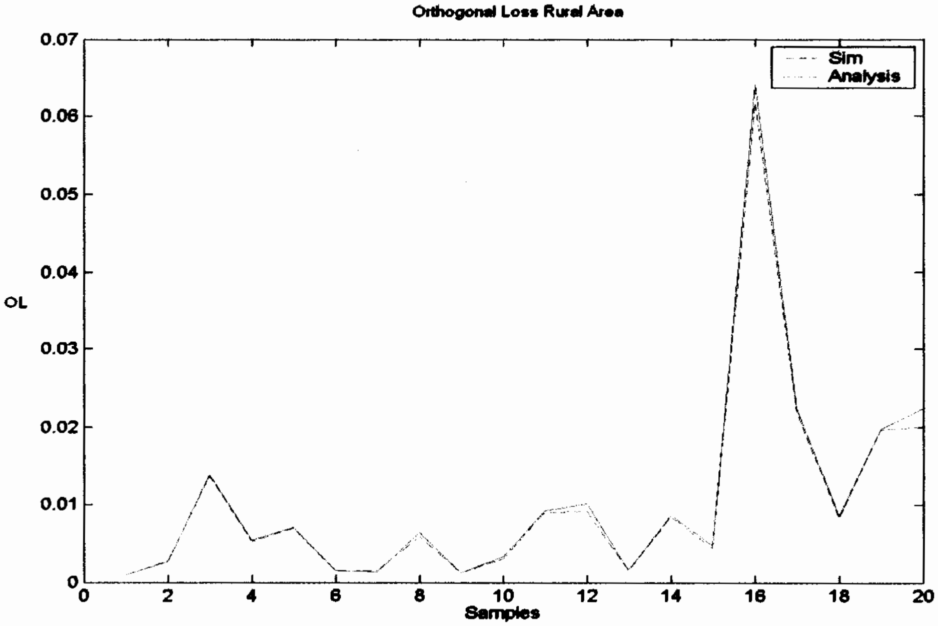

Figure 1: Orthogonal Loss Factor in Rural Area

As shown above analysis and simulations are quite in agreement. Next a comparison is shown in Figure 2 with other expressions in literature. Comparison is made between analysis and simulations curves presented in this thesis with two other expressions of Orthogonal loss factor. One is presented by Passerini and Falciasecca [10] and second one is presented by Mehta [14]. The solid line shows the analysis curve, diamonds are values from simulation, the doted line show curves of Passerini OLF expression and dashed line is the curve from OLF expression by Mehta. In Figure 2 using Rural Area environment comparison is show between expressions. Expression by Passerini shows lowest values, expression by Mehta gives values higher than Passerini but lower than Analysis curve. Only analysis expression is equal to the simulation of orthogonal loss factor. So the expression presented in this thesis matches the simulation and other expression significantly deviates from simulation.

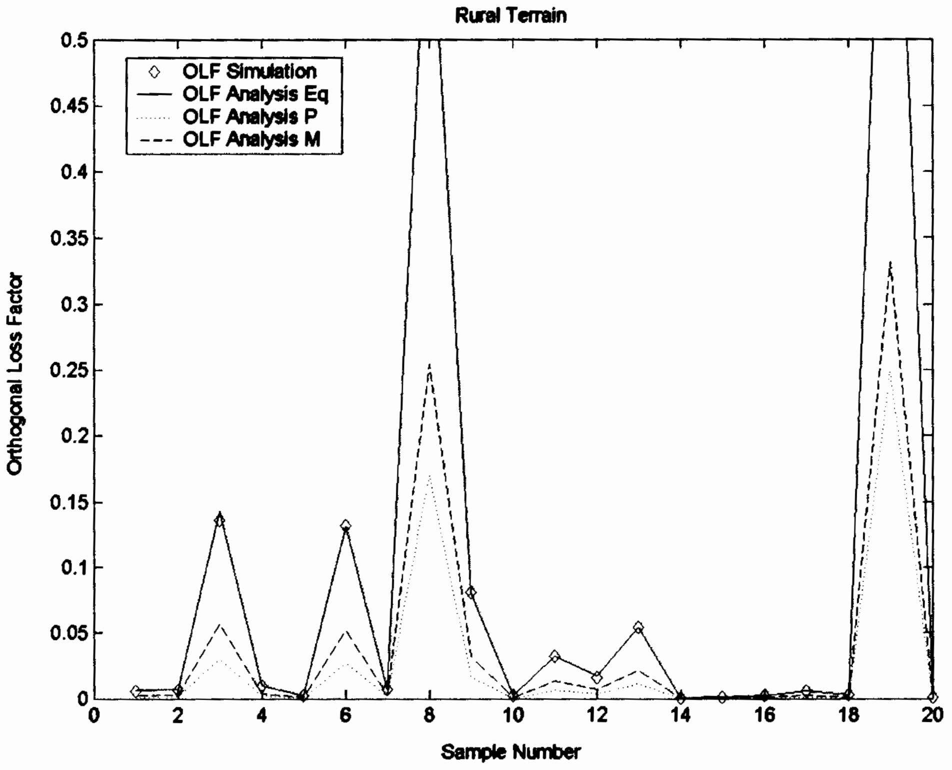

Figure 2: Comparison of expressions in Rural Area

Time traces of Orthogonal Loss factor using Urban Area multipaths environment are plotted in Figure 3. Results of simulation and analysis are plotted. A good match in simulation and analysis is observed. For Urban Area profile, values of Orthogonal Loss are very high as compared to Rural Area. Simulation, dotted graph is a plot of Analysis Equation(3.2). In this equation instantaneous values of Interference Power I and Signal power S are used. Analysis, solid graph is a plot of OLF Formula(3.22). In this formula only instantaneous channel parameters are need. Simulation and Analysis are perfectly matched. So OF Formula can be used for further study of CDMA orthogonality.

Time traces of Orthogonal Loss using Hilly Area Environment are plotted in Figure 5. Results of simulation and analysis are plotted. A good match in simulation and analysis is observed. For Hilly Area profile, values of Orthogonal Loss comparatively higher than

Rural Area and lower than Urban Area. Simulation, dotted graph is a plot of Equation (3.2). In this equation instantaneous values of Interference Power I and Signal power S are used. Analysis, solid graph is a plot of Orthogonal Loss Formula (3.22). In this formula only instantaneous channel parameters are need. Simulation and Analysis are perfectly matched. So Orthogonal Loss Formula can be used for further study of CDMA. Figure 6 gives comparison of different OLF expressions in literature as show above for Rural Area and Urban Area. Values obtained from Analysis expression by Mehta [14] and Passerine [10] do not match with analysis and simulation results shown solid line and diamonds respectively. Formula (3.22) shows more accurate results than results of Mehta [14] and Passerine.

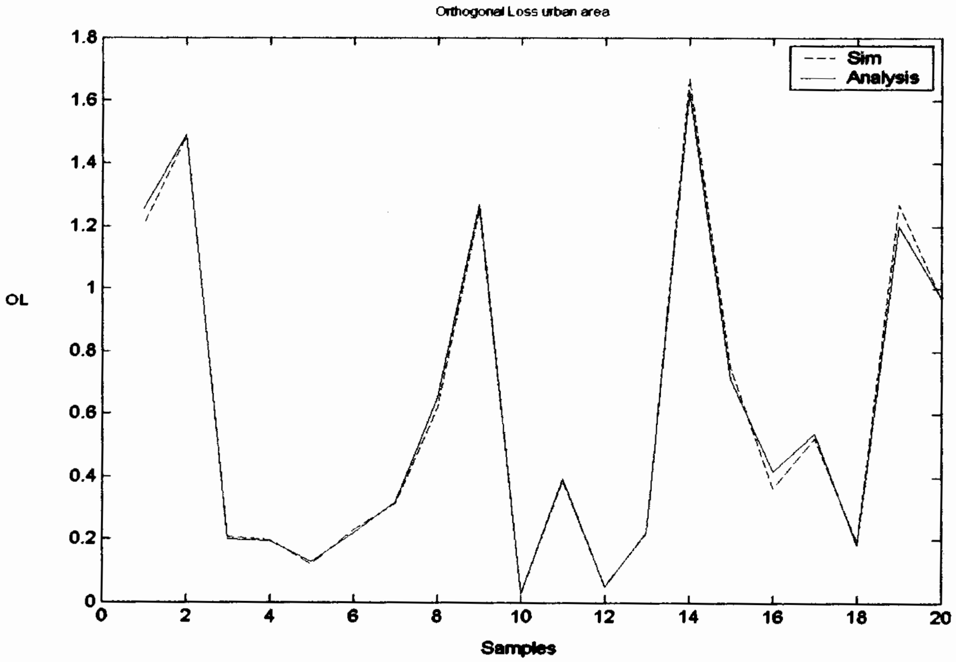

Figure 3: Orthogonal Loss factor in Urban Area

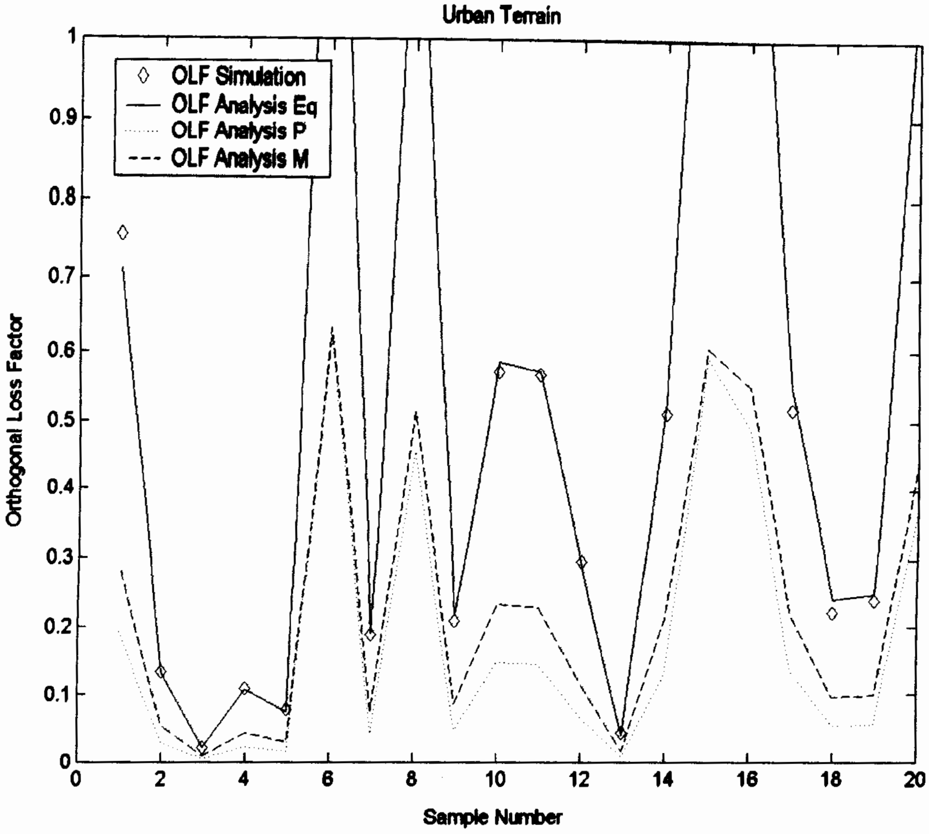

Figure 4: Comparison of expressions in Urban Area

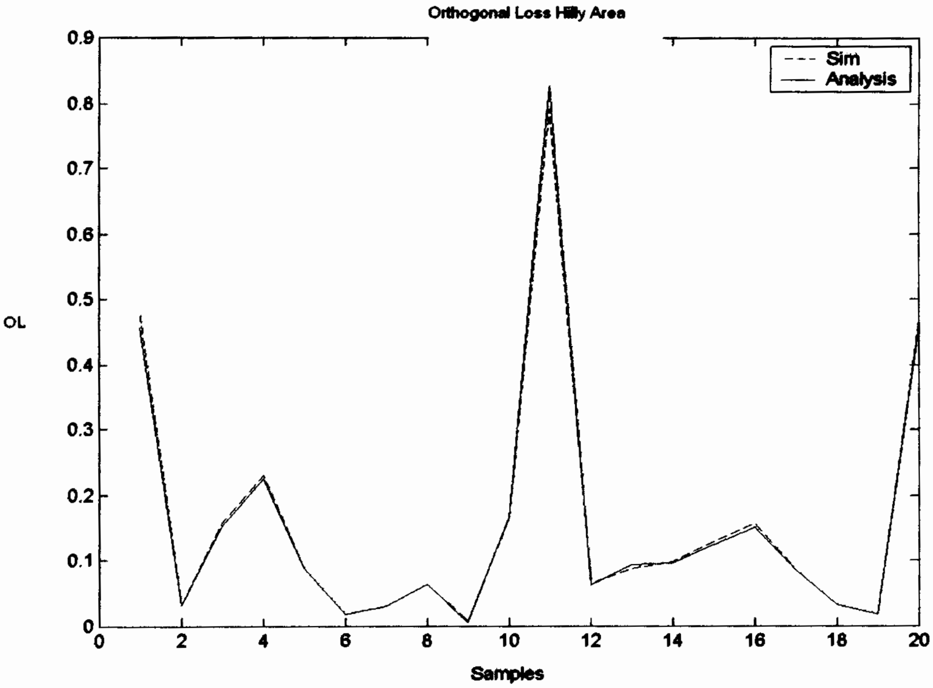

Figure 5: Orthogonal Loss Factor in Hilly Area

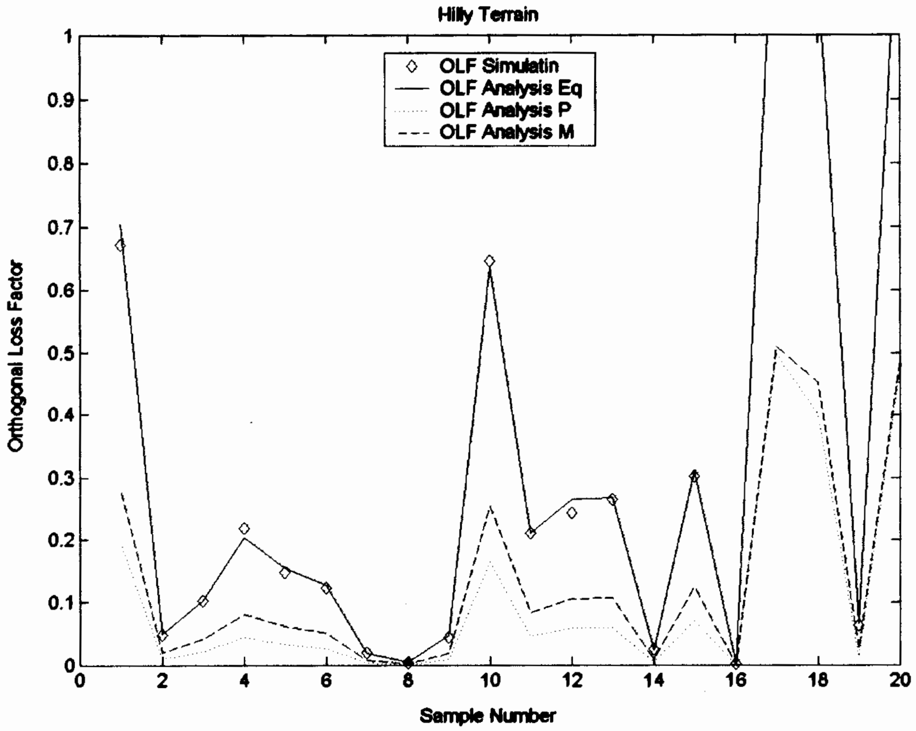

Figure 6: Comparison of expressions in Hilly Area

In the Figure 7 Cumulative Distribution function CDF of Rural Area, Urban Area and Hilly Area are plotted for comparison. It is obvious that Rural Area has lowest Orthogonal loss values, Hilly Area profile has higher values of Orthogonal loss than Rural Area profile. Urban Area channel profile has highest values of Orthogonal Loss that shows a substantial loss of orthogonality. Above statistics of Orthogonal loss are collected using Orthogonal Loss formula (3.22) by using instantaneous values of channel gains. Rural area has lowest orthogonal loss values. So very low interference will be experience by the user. Hilly area has relative high values of Orthogonal Loss factor, resulting a high interference. Scenario in Urban area is worst. Very high values of Orthogonal Loss Factor are observed and so high interference.

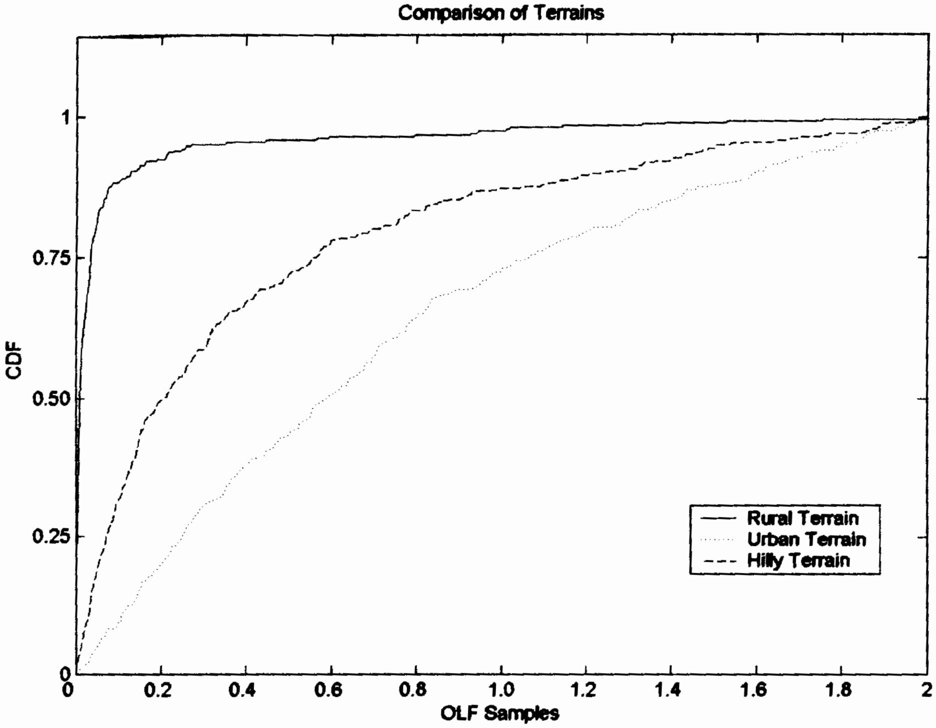

Figure 7: Comparison of OLF in different types of Area

Chapter 5

Conclusion

Code Division Multiple Access is highly dependent on orthogonality of codes. In multipaths path environment due to loss of synchronization among the codes resulted in loss of orthogonality. A quantitative measure of orthogonality is analyzed and named as orthogonal loss factor. Expression derived for orthogonal loss factor in this thesis is in agreement with simulation. OLF expression is compared with other expressions in the literature and a significant improvement is observed. OLF expression is used for comparing different channels power delay profiles. And this expression is found useful in comparing different channel conditions and gives an idea how much interference is experienced by the users.

Appendix

Simulation Code

```
%    OLF Simulation Vs OLF Analysis   %
clear
for (chv=1:3)
 V=0;
for (n=1:350)
%msequenceGFO5 % returns x1 real gold sequence period 31
%x1;


%CodesVectors
lt=0;
M=4;
P=10;
Pi=1;
Ptot=3*Pi;
I
Si=1;
IoA=1;
SiA=1;
if (chv ==1)
raChannel
end
if (chv==2)
uaChannel;
end
if (chv==3)
haChannel;
end
for m=1:10
Data
IoSim20060713;        % returns Io=Io*P;
SiSim20060713;        % returns Si
IoV(m)= Io;
SiV(m)= Si;
end
Io=mean(IoV);
Si=mean(SiV);
```

```
aw=a.*(w);
sumaw=(sum (aw))^2;
suma=sum (a .* a);
sumw=sum (w .* w);

IoAnalysis2;      % returns OLNum=IoC * P ;
SiAnalysis;       % returns SiA=((M)*sqrt(Pi)*(a(1)*a(1)+a(2)*a(2)))^2;
Pi;
SiA=SiA
Si=Si
Io
OLNum
OL= M*Pi*Io*sumaw/(Si * (Ptot - Pi)* suma * sumw);               %Io 2.5 Si
OLA=M*Pi*OLNum*sumaw/(SiA * (Ptot - Pi)* suma * sumw);           %IoA OLNum SiA
raOL= OL;
OLA = OLA;

if (V==1)
raOLV= [raOLV raOL];
OLAV= [OLAV OLA];
end

if (V==0)
raOLV=raOL;
OLAV=OLA;
V=1;
end
end

if (chv==1)
figure(1)
plot (raOLV(1:20),'g--')
hold on;
plot (OLAV(1:20), 'g')
hold off;

end
if (chv==2)
figure(2)
plot (raOLV(1:20),'r--')
hold on;
plot (OLAV(1:20), 'r')
hold off;
end

if (chv==3)
```

```
figure(3)
plot (raOLV(1:20),'b--')
hold on;
plot (OLAV(1:20), 'b')
hold off;
end

if (chv==1)
figure(4)
pdfplot([raOLV lt] ,'g--');
hold on;
pdfplot([OLAV lt],'g');
hold off;
figure(7)
pdfplot([OLAV lt],'g');
end

if (chv==2)
figure(5)
pdfplot([raOLV lt] ,'r--');
hold on;
pdfplot([OLAV lt],'r');
hold off;
figure(7)
hold on
pdfplot([OLAV lt],'r');
end

if (chv==3)
figure(6)
pdfplot([raOLV lt] ,'b--');
hold on;
pdfplot([OLAV lt],'b');
hold off;
figure(7)
hold on
pdfplot([OLAV lt],'b');
hold off;
end
end

%  CodesVectors   %

H1=ones(1,1);
H2=[H1 H1; H1 bitcmp(H1,1)];
H4=[H2 H2; H2 bitcmp(H2,1)];
```

```
H8=[H4 H4; H4 bitcmp(H4,1)];
H16=[H8 H8; H8 bitcmp(H8,1)];
H32=[H16 H16; H16 bitcmp(H16,1)];
H64=[H32 H32; H32 bitcmp(H32,1)];


H4p=-2*H4 +1;          %polar  0-->1  1-->-1
msequenceGFO5Gold; % returns x1   msequence [1 x 31]   % x1 = x1 .* x2
%gold sequence of order 5


mseq=CONCATMAT(x1,4);
% CONCATMAT() repeats and concatenate vector number of times
H4p=CONCATMAT(H4p,31);
concat2=H4p(2,:) .* mseq(1:124);
concat3=H4p(3,:) .* mseq(1:124);
concat4=H4p(4,:) .* mseq(1:124);


%           Concat5H4     %
% Generation of concatenation of msequence of order 5 and Hadamard H4
clear
H1=ones(1,1);
H2=[H1 H1; H1 bitcmp(H1,1)];
H4=[H2 H2; H2 bitcmp(H2,1)];
H8=[H4 H4; H4 bitcmp(H4,1)];
H16=[H8 H8; H8 bitcmp(H8,1)];
H32=[H16 H16; H16 bitcmp(H16,1)];
H64=[H32 H32; H32 bitcmp(H32,1)];
H64p=[H64 H64 H64];

H4p=-2*H4 +1;            %polar  0-->1  1-->-1 H4p matrix  [4 x4]
msequenceGFO5;           % returns x1   msequence [1 x 31]
%x1

H4p=CONCATMAT(H4p,31);
mseq=CONCATMAT(x1,4);
 concat1=mseq.*H4p(1,:);   %8 time period of msequence
                           %and 62 times hadamard code
concat2=mseq.*H4p(2,:);    %8 time period of msequence
                           %and 62 times hadamard code

concat3=mseq.*H4p(3,:);    %8 time period of msequence
                           %and 62 times hadamard code
concat4=mseq.*H4p(4,:);    %8 time period of msequence
                           %and 62 times hadamard code
```

```
%     CONCATMAT            %
function CONCATMAT=matrixconcatination(MAT,n)
CONCATMAT=MAT;

if (n > 1)
for(i=2:n)

CONCATMAT=[MAT CONCATMAT];
end

end
%            Data      %
% calculating the user power
 %Pi= mean(concat2(1:124) .* concat2(1:124));
 Ptot=3*Pi ;

%udata2 user1data
ud2=randsrc(1,31,[1,-1]);
udata2 =ud2(1)*[1 1 1 1];
for (i=2:31)
udata2=[udata2 , ud2(i)*[1 1 1 1]];
end


%udata3 user1data
ud3=randsrc(1,31,[1,-1]);
udata3 =ud3(1)*[1 1 1 1];
for (i=2:31)
udata3=[udata3 , ud2(i)*[1 1 1 1]];
end

%udata4 user1data
ud4=randsrc(1,31,[1,-1]);
udata4 =ud4(1)*[1,1,1,1];
for (i=2:31)
udata4=[udata4 , ud4(i)*[1 1 1 1]];
end

udata2spread=concat2.*udata2;
udata3spread=concat3.*udata3;
udata4spread=concat4.*udata4;
```

```
%           haChannel %
ha=[ 0.4365 0.0707 0.0169 0];
ha=raylrnd(ha,1,4);

a=ha(1:4);
w=a(1:4);


%           IoAnalysis2    %
be=0;  om=0;
M=4;  K=2;
adelay=[0,1,2,3];
wdelay=adelay;
Nf=4;
Nt=4;
TC=1;
t1=0;
i=1;
%a=[0.3 0.2];
for (Nf=1:4)
 Ioo=0;
 for Nt=1:4
 if wdelay(Nf) == adelay(Nt)
 Ioo(i)=0;
 i=i+1;
 end
if wdelay(Nf) ~= adelay(Nt)
Ioo(i)=a(Nt)*w(Nf)*w(Nf)*w(Nt)*K*M;
i=i+1;
end
 end

IoF(Nf)=sum(Ioo);
i=1;
end

IoF;
IoC=mean(IoF);
%IoC=M*M*(Ptot - Pi)*mean(IoF)
OLNum=IoC*P;

%           IoSim20060713   %
%udata2spread=concat2.*udata2;
%udata3spread=concat3.*udata3;
```

```
%udata4spread=concat4.*udata4;

I1= udata3spread + udata2spread;
I2=[I1 I1];
dI1=[zeros(1,1) I1 zeros(1,123)];     %delay I by 1 chips
dI2=[zeros(1,2) I1 zeros(1,122)];     %delay I by 2 chips
dI3=[zeros(1,3) I1 zeros(1,121)];     %delay I by 3 chips

C0=[concat4 zeros(1,124)];                  %delay concat2C by 1 chips
C1=[zeros(1,1) concat4 zeros(1,123)];       %delay concat2C by 1 chips
C2=[zeros(1,2) concat4 zeros(1,122)];       %delay concat2C by 2 chips
C3=[zeros(1,3) concat4 zeros(1,121)];       %delay concat2C by 3 chips


I = a(1)*I2 + a(2)*dI1 + a(3)*dI2 + a(4)*dI3;
N= (w(1))*(C0) + (w(2))*(C1) + (w(3))*(C2) + (w(4))* (C3);
finger1=I .* (w(1)*C0);
finger2=I .* (w(2)*C1);
finger3=I .* (w(3)*C2);
finger4=I .* (w(4)*C3);

for(i=1:20)
finger1Io(i)=sum(finger1((1:4)+4*i));
finger2Io(i)=sum(finger2((2:5)+4*i));
finger3Io(i)=sum(finger3((3:6)+4*i));
finger4Io(i)=sum(finger4((4:7)+4*i));
end
RakeIo1=mean(finger1Io .* finger1Io);
RakeIo2=mean(finger2Io .* finger2Io);
RakeIo3=mean(finger3Io .* finger3Io);
RakeIo4=mean(finger4Io .* finger4Io);
Io = (RakeIo1+RakeIo2+RakeIo3+RakeIo4)/4;
Io=Io*P;

%          msequenceGFO5Gold     %
% mseq1
x1=zeros(1,2^5-1);
x1(1:5)=[1 1 1 1 1];
j=sqrt(-1);
%x  GF order 5 Length=31 GF=X^5+X^4+X^3+X+1
for(i=0:(2^5-7))
 x1(5+i+1)=mod(x1(4+i+1)+x1(3+i+1)+x1(1+i+1)+x1(i+1),2);
end
x1=-2*x1 +1;  %[0,1] --> [1,-1]
%mseq2  it is shifted version of x1
```

```
x2=zeros(1,2^5-1);
x2(1:5)=[1 0 1 0 1];
j=sqrt(-1);
%x  GF order 5 Length=31 GF=X^5+X^4+X^3+X+1
for(i=0:(2^5-7))
 x2(5+i+1)=mod(x2(4+i+1)+x2(3+i+1)+x2(1+i+1)+x2(i+1),2);
end
x2=-2*x2 +1;  %[0,1] --> [1,-1]
x1=x1 .* x2;

%           pdfplot      %
function pdfplot(dataV,color)
N= hist(dataV,20)
[r c]=size(N)
C=0;
for (n=1:c-1)
   C(n)=sum( N(1:(n+1)));
end
plot(C,color)

%           raChannel           %
% rural area cost 207
ra=[1.0000    0.0400    0.0016  0];
ra=raylrnd(ra,1,4);
a=ra(1:4);
w=a;

%           SiAnalysis          %
SiA=((M)*sqrt(Pi)*(a(1)*a(1)+a(2)*a(2)+a(3)*a(3)+a(4)*a(4)))^2;

%           SiSim20060713    %
S1= udata2spread;
S11=[S1 S1];
Si=Pi*(a(1)*a(1)*sum(S1 .* S1)/31 +a(2)*a(2)*sum(S1 .* S1)/31+ a(3)*a(3)*sum(S1 .*
S1)/31 +a(4)*a(4)*sum(S1 .* S1)/31)^2;
% number of symbols 31

%           uaChannel     %
% urban area cost 207
ua= [1.0000    0.2047    0.1966    0.0030]
ua=raylrnd(ua,1,4);
a=ua(1:4);
w=a(1:4);
```

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