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Simulations of Implementation of Advanced Communication Technologies

Ivy Yousuf Moutushi

Thesis submitted to the Statler College of Engineering and Mineral Resources at West Virginia University

in partial fulfillment of the requirements for the degree of

Master of Science in Electrical Engineering

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Morgantown, West Virginia 2023

Keywords: CDMA, MIMO, LDPC

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Abstract

Simulations of Implementation of Advanced Communication Technologies

by

Ivy Yousuf Moutushi

Wireless communication systems have seen significant advancements with the introduction of 3G, 4G, and 5G mobile standards. Since the simulation of entire systems is complex and may not allow evaluation of the impact of individual techniques, this thesis presents techniques and results for simulating the performance of advanced signaling techniques used in 3G, 4G, and 5G systems, including Code division multiple access (CDMA), Multiple Input Multiple Output (MIMO) systems, and Low-Density Parity Check (LDPC) codes. One implementation issue that is explored is the use of quantized Analog to Digital Converter (ADC) outputs and their impact on system performance.

Code division multiple access (CDMA) is a popular wireless technique, but its effectiveness is limited by factors such as multiple access interference (MAI) and the near far effect (NFE). The joint effect of sampling and quantization on the analog-digital converter (ADC) at the receiver's front end has also been evaluated for different quantization bits. It has been demonstrated that 4 bits is the minimum ADC resolution sensitivity required for a reliable connection for a quantized signal with 3- and 6-dB power levels in noisy and interference-prone environments.

The demand for high data rate, reliable transmission, low bit error rate, and maximum transmission with low power has increased in wireless systems. Multiple Input Multiple Output (MIMO) systems with multiple antennas at both the transmitter and receiver side can meet these requirements by exploiting diversity and multipath propagation. The focus of MIMO systems is on improving reliability and maximizing throughput. Performance analysis of single input single output (SISO), single input multiple output (SIMO), multiple input single output (MISO), and MIMO systems is conducted using Alamouti space time block code (STBC) and Maximum Ratio Combining (MRC) technique used for transmit and receive diversity for Rayleigh fading channel under AWGN environment for BPSK and QPSK modulation schemes. Spatial Multiplexing (SM) is used to enhance spectral efficiency without additional bandwidth and power requirements. Minimum mean square error (MMSE) method is used for signal detection at the receiver end due to its low complexity and better performance. The performance of MIMO SM technique is compared for different antenna configurations and modulation schemes, and the MMSE detector is employed at the receiving end.

Advanced error correction techniques for channel coding are necessary to meet the demand for Mobile Internet in 5G wireless communications, particularly for the Internet of Things. Low Density Parity Check (LDPC) codes are used for error correction in 5G, offering high coding gain, high throughput, low latency, low power dissipation, low complexity, and rate compatibility. LDPC codes use base matrices of 5G New Radio (NR) for LDPC encoding, and a soft decision decoding algorithm is used for efficient Frame Error Rate (FER) performance. The performance of LDPC codes is assessed using a soft decision decoding layered message passing algorithm, with BPSK modulation and AWGN channel. Furthermore, the effects of quantization on LDPC codes are analyzed for both small and large numbers of quantization bits.

Keywords: 3G, 4G, 5G, CDMA, MAI, NFE, MMSE, ADC, SISO, SIMO, MISO, MIMO, STBC, SM, MRC, LDPC.

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Notation

We have used the following notation and symbols throughout this thesis.

1G	First Generation
2G	Second Generation
3G	Third Generation
4G	Fourth Generation
5G	Fifth Generation
UMTS	Universal Mobile Telecommunication Service
LTE	Long Term Evolution
NR	New Radio
WiMAX	Worldwide Interoperability for Microwave Access
Wi-Fi	Wireless Fidelity
3GPP	Third Generation Partnership Project
CDMA	Code Division Multiple Access
WCDMA	Wideband Code Division Multiple Access
MAI	Multiple Access Interference
NFE	Near Far Effect
ADC	Analogue to Digital Converter
DAC	Digital to Analogue Converter
MMSE	Minimum Mean Square Error
MIMO	Multiple Input Multiple Output
SISO	Single Input Single Output
SIMO	Single Input Multiple Output
MISO	Multiple Input Single Output
MRC	Maximum Ratio Combining
STBC	Space time block code
OSTBC	Orthogonal Space time block code
QOSTBC	Quasi Orthogonal Space time block code
SM	Spatial Multiplexing
ZF	Zero Forcing
ML	Maximum Likelihood
CSIT	channel state information at transmitter
CSIR	channel state information at receiver
SNR	signal-to-noise ratio
SIR	signal to interference ratio
BER	bit error rate
FER	frame error rate
AWGN	Additive White Gaussian Noise

BPSK	Binary Phase Shift Keying
QPSK	Quadrature Phase Shift Keying
QAM	Quadrature Amplitude Modulation
ARQ	Automatic Repeat Request
FER	Forward Error Correction
LDPC	Low density parity check
FDD	Frequency Division Duplex
GSM	Global System for Mobiles
SMS	Short Message Service
OFDM	Orthogonal Frequency Division Multiplexing
TD-SCDMA	Time Division Synchronous Code Division Multiple Access
IP	Internet Protocol
PN	Pseudo random noise
DS	Direct Sequence
DSSS	Direct sequence spread spectrum
FH	Frequency hopping
FM	Frequency Modulation
GP	Processing Gain
NRZ	Non-Return to zero
FDMA	Frequency Division Multiple Access
TDMA	Time Division Multiple Access
PAM	Pulse Amplitude Modulation
BF	bit flipping
SPA	sum product algorithm
MSA	min sum algorithm

Chapter 1

Introduction

Signaling technologies play a critical role in enabling communication between devices and infrastructure in 3rd, 4th, and 5th generation wireless systems. Code Division Multiple Access (CDMA) is a key signaling technology used in 3G networks, allowing multiple users to share the same frequency band by assigning unique codes to each user. Multiple Input Multiple Output (MIMO) is a signaling technology used in 4G and 5G networks, which uses multiple antennas to transmit and receive data, improving network speed and capacity. In 5G networks, MIMO is enhanced with beamforming, which uses directional antennas to improve network performance further. Another important signaling technology in 5G is the Low-Density Parity-Check (LDPC) code, which is a powerful error-correcting code used to ensure that data is transmitted accurately and reliably. Overall, signaling technologies like CDMA, MIMO, and LDPC play a crucial role in enabling the high-speed, low-latency, and reliable communication that is required for modern wireless networks.

1.1 Code Division Multiple Access (CDMA)

As the demand for wireless communication rapidly grew, the use of CDMA techniques enabled systems to achieve high data capacity and spectral efficiency without causing a decrease in the overall system capacity of wireless communication systems. With the use of spread spectrum and its characteristics the CDMA system results in many benefits [1]. A basic problem that may arise is the multipath fading and interference from other users which can be effectively mitigated by spread spectrum for its wide bandwidth and spreading gain, resulting in higher system capacity [1]. Multiple Access Interference (MAI) is a limitation to the performance and capacity of CDMA systems. MAI occurs when CDMA systems process each user's signal separately, but the signals from other users are treated as noise. The inherent interference suppression capability of CDMA, as measured by the processing gain, protects against interference from other users and enables detection of the desired signal. [2]. When more users interfere with a CDMA system, the resulting equivalent noise reduces performance and increases the Bit Error Rate (BER). In some cases, a high-power user may overpower a lowpower user and cause interference that affects the latter's reception. [2]. MAI causes the Near-Far Effect (NFE), whereby users near the receivers receive higher power levels than those far away. This results in weak signals experiencing performance degradation [2]. CDMA systems are highly susceptible to the Near-Far Effect (NFE) and implementing power control has proven to be an effective way to mitigate NFE. However, adding power control increases the complexity of the system. Therefore, the multiuser detection of CDMA systems increase capacity but alleviate the NFE and MAI which makes decision based on the overall received signals for all users by tracking and demodulating all the users signals simultaneously [1,2]. The effects of A/D conversion on the overall system performance considering the sampling and quantization effects on direct conversion of CDMA systems performances pointed out the robustness of CDMA with respect to quantization noise and high sensitivity to sampling jitter which severely affect the system operations [3]. The quantizer is designed to optimize Minimum Mean Squared Error (MMSE). Moreover, to ensure that the input is within the

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operating range of the ADC, the received signal must be properly scaled [4]. Since the power of the desired signal varies as the power of the MAI varies the performance of the receiver is affected by this scaling [4]. The performance degradation of the correlation receiver with the quantization effects is evaluated. Hence, CDMA was a popular technology for 3rd generation systems, but is used less directly in 4th and 5th generation systems (although the interference mitigation concepts are employed in these).

1.2 Multiple Input Multiple Output (MIMO)

Wireless applications have significantly increased the requirement of higher data rate and highspeed stable communications with the minimum bandwidth and power at the transmitters. The simplest communication system consists of a single antenna at both transmitter and receiver side which gives high quality and reliable information transmission that covers short distance [5]. However, for long distances there is more power consumption so the new technique MIMO which has multiple transmitter and multiple receiver antenna is evolved that achieves higher spectral efficiency that improves the system coverage with diversity gain to get low Bit error rate (BER) and the performance of the communication channel by taking the advantage of the multipath effects like fading that improves the quality of the received signal [5,6]. MIMO is important for modern wireless communication standards such as IEEE 802.11n(Wi-Fi), 4G, LTE and WiMax [7]. MIMO system enhances the two aspects: reliability and capacity of the communication channel with the help of two techniques Spatial Diversity and Spatial Multiplexing [5,6]. The multiple copies of the same signal that transmits/receives over different channels can be combined to improve the SNR which increases the reliability of the channel. Space time coding is one of the techniques that employs spatial diversity, and its special case is the Alamouti code which requires channel state information at receiver (CSIR) only and without the bandwidth expansion and has relatively low computational complexity at the receiver [5]. Space time coding jointly encodes the data streams which leads to reduction in symbol error rate due to channel fading and simultaneously improves the diversity gain and communication link [8]. To obtain high data rates, a higher order modulation method along with diversity gain is applied in case of space time coding [8]. On the other hand, Spatial Multiplexing technique which is responsible to increment spectral efficiency of MIMO systems by transmitting independent streams from independent antennas by exploiting multipath propagation and without extending the channel bandwidth [5]. The capacity gain of MIMO channel is increased with the different spatial dimensions of the channel that utilizes different data streams which are distinguishable [8]. The linear equalizer such as Minimum Mean Square Error (MMSE) equalizers is used for low computational complexity to mitigate the inter symbol interference which is caused by the data streams that is corrupted by noise interfere with each other at the receiving antenna side [8]. The MIMO spatial multiplexing with MMSE detector is used for different antenna configurations and different modulation schemes are analyzed [8].

1.3 Low Density Parity Check (LDPC) Code

In Wireless Mobile communication, the main challenge is to achieve a reliable and error free transmission of data in the communication system. There are two basic error control strategies

used to increase the reliability of data transmission from information source to destination which are Automatic Repeat Request (ARQ) and Forward Error Correction (FER) [9]. The preference of FEC is greater than ARQ as ARQ schemes results in unnecessary wastage of the channel bandwidth due to retransmission of unreliable data frames [9]. On the contrary, the FEC performs the dual function of both error detection and correction which combines the idea of adding redundant bits to message bits known as parity bits. Channel codes are being produced by Shannon Theorem that gave rise to many errors correcting codes which is divided into Linear block codes and Convolutional Codes [9].

The 3rd Generation Partnership Project (3GPP) specifies that Polar codes and LDPC codes are two varieties of channel codes utilized for Fifth generation (5G) New Radio (NR) [10]. Polar codes are applied to 5G NR control channels whereas LDPC codes are suitable due to its high throughput, low latency, better spectral efficiency, and low decoding complexity. LDPC is a linear block code that provides better BER performance close to Shannon limit due to message passing decoding algorithm used in LDPC decoder [9]. LDPC codes have several advantages that make them preferable to Turbo Codes in various applications. For instance, they demonstrate better performance when utilized with long block lengths, have low complexity, and offer high coding gain. Furthermore, LDPC codes are flexible since they can be used with different block sizes and code rates, which makes them suitable for designing base graphs. The size of the base matrix can also be altered to enhance their efficiency. Additionally, the double diagonal structure of the base graph facilitates more efficient LDPC encoding. Due to these benefits, LDPC codes have replaced Turbo Codes in various applications, including the DVB-S2 video

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standard for satellite communication in digital televisions, mobile communication systems, data storage systems, and optical communication systems [9,10,11]. LDPC code for 5G New Radio (NR) uses two base parity check matrices called Base Graph that employ corresponding to the input length and code rate [11]. LDPC uses two types of decoding algorithms- hard decision decoding and soft decision decoding which offers a particular tradeoff between error performance and decoding complexity [9,12]. The messages passed in hard decision decoding contains the actual value of bits. But in soft decision decoding the messages passed is the probability value associated with the occurrence of a particular bit [9]. The decoding process is performed by iteratively exchanging messages between the nodes and through the edges in the Tanner graph representing code [12].

Therefore, the soft decision decoding layered message passing algorithm for LDPC code using BPSK modulation and AWGN channel is considered to evaluate the performance of Frame Error Rate verses SNR. Also, the method is extended to the soft decision (quantized) iterative decoding algorithms to estimate the performance of the quantization effect on LDPC codes and compare its results for small number of quantization bits with large number of quantization bits.

1.4 Thesis Outline

Over the past few decades, there is a massive growth in the technologies of mobile and wireless networks and how it evolved with the new generation technologies every ten years such as from 3G Universal Mobile Telecommunication Service (UMTS), 4G Long Term Evolution (LTE) to the present 5G New Radio (NR). With the advancements in the technologies in every new generation there is an improvement in the services provided in terms of speed, connectivity and performance which are evaluated using the performance metrics for error rate, data rate, spectral efficiency, energy efficiency, computational complexity, throughput, latency, and reliability in the connection. The purpose of the thesis is to give the overview of some of the advanced signaling technologies such as the CDMA, MIMO and LDPC code which are used in 3G, 4G and 5G systems to evaluate the performance with quantization effects and provide solutions in each of its aspect. The remainder of the thesis is organized as follows.

In chapter 2, the background information on basic concepts of the spread spectrum and CDMA systems is briefly described along with its important features. Then the simulation of Bit Error Rate for BPSK, QPSK, Synchronous CDMA, and Asynchronous CDMA is performed and compared with the theoretical result to see the performance metrics. The simulation methods and the system parameters are elaborated in detail.

In chapter 3, the simulation of the Bit Error Rate for Asynchronous CDMA for different parameters is performed and observed to see the performance metrics. The key factors of CDMA systems such as the multiple access detection for Asynchronous CDMA systems for different processing gain also for Bandpass signals the same measurements done and then the near far effect of Asynchronous CDMA systems for 2 and 4 users simulation method discussed, compared, and analyzed. In chapter 4, the things that are different comparatively to the previous cases is that the receive signal is now quantized i.e., how the analog to digital converter would quantize the signal over the range of interest which is during the model of quantization how the number of bits of quantization are being adjusted for the range of quantization that accommodate more signals so the quantizers does not just saturate. Besides what resolution is needed depending on different levels of near far problem and how to adjust the bound of the quantizer to make sure it saturates for the quantization of signals with equal power in near far problem. The analysis of reception of CDMA systems with quantization is observed for different characteristics. The simulation methods and the system models are elaborated in detail.

In chapter 5, it mainly focuses on achieving the reliability and high data rate through MIMO system with space time block code (STBC) and spatial multiplexing (SM) techniques are used. Initially it describes the properties and some prime features of SISO, SIMO, MISO, MIMO, STBC, Alamouti STBC method, Spatial Multiplexing, and the different types of equalizers. It shows and discusses the comparison for the no diversity, transmit diversity, receive diversity and 2×2 MIMO system using Alamouti STBC coded cases through Rayleigh fading channel under AWGN environment for BPSK and QPSK modulation techniques. It presents the performance of spatial multiplexing based on the Multiple Input Multiple Output (MIMO) system with respect to bit error rate verses signal to noise ratio for different modulation schemes (like BPSK, QPSK, !6 QAM and 64 QAM) and detection techniques of minimum mean square error (MMSE) is used and to evaluate their performance it uses 1×1, 2×2,4×4 and 8×8 antenna configurations.

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In chapter 6, it focuses on the key concepts of LDPC codes, their encoding and decoding algorithms. It evaluates the Frame Error Rate (FER) performance of soft decision decoding algorithms of Low-Density Parity Check (LDPC) codes on AWGN channel for 1000 number of blocks and different Signal to Noise ratio using BPSK modulation. Also, it has considered the method of uniform quantization and analyzed and deduced its effects for computational complexity based on real valued operations. To quantify its initial message, the variable messages and check messages are converted into integers after each iteration. Then the layered message passing algorithm based on integer arithmetic for BPSK modulation is implemented.

Finally, the thesis concludes in chapter 7, which summarizes the thesis and is an extension of some ideas of future work are presented.

Chapter 2

Spread Spectrum, CDMA Communication Environment and Simulation Methods

2.1 EVOLUTION OF WIRELESS COMMUNICATIONS

2.1.1 1G (1st Generation)

In 1980 the 1st generation-based communication systems began. These systems featured the mobile phone systems, known as 'cellular mobile radio telephone' [15]. These generation-based systems were analog voice signaling, it used an FDD scheme, and the coverage area was small.

2.1.2 2G (2nd Generation)

In 1990 the 2nd generation-based communication systems began, and the technology is still in use. The 2G communication system features digital voice encoding such as GSM and CDMA [15]. 2G technology has slowly improved since its inception, with packet routing, increased bandwidth that has moderate mobile data service, and the introduction of multimedia [15]. It supports both voice and SMS and provides high data rate and large area coverage.

2.1.3 3G (3rd Generation)

The 3rd generation systems are relevant to portable wireless and fixed wireless as it is considered for mobile wireless. A 3G system can be operated from any location such as the

military, the earth's office, commercial and personal aircraft, personal vehicles, space stations which includes use in homes, and spacecraft [15]. 3G offers potential connection to users at all places as the internet system is improved, which is better and has high capacity. It offers high speed wireless internet and the connection used was UMTS and WCDMA. Another challenge faced by 3G services is competition from other high-speed wireless technologies, especially mobile WiMAX, and the ability to roam between different kinds of wireless networks [15].

2.1.4 4G (4th Generation)

The stage of mobile communications will be super ceded by the 4G which is the fourthgeneration wireless. The combination of Wi-Fi and WiMAX are used by 4G networks that can be defined as wireless ad hoc peer-to-peer networking with high usability personalization, global roaming, distributed computing, and support multimedia at a low transmission cost [15].4G networks will use end-to-end Internet Protocol (IP) and distributed architecture. Every device will be both a transceiver and a router for other devices in the network eliminating the spokeand-hub architecture weakness of 3G cellular systems [15]. The network coverage and capacity will be dynamically changing, giving flexibility to accommodate the changing user patterns with reasonable QoS. Users will automatically move away from congested routes to allow the network to automatically and dynamically self-balance [15]. When 4G is fully implemented which enables to perform computing, in which simultaneous connections to multiple highspeed networks provide handoffs throughout a geographical area [15]. Network operators may employ technologies such as wireless mesh networks to efficiently distribute both spectrum and network traffic to ensure connectivity thus enhancing the useability [15]. Technologies

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employed by 4G may include OFDM, MIMO technologies, UMTS and TD-SCDMA [15]. All these technologies are typified by packet-switched transmission protocols and high data rates of transmission. By contrast, 3G technologies are a combination of packet and circuit-switched networks.

2.1.5 5G (5th Generation)

At present we have fifth generation (5G) networks. This generation involves the development of new standards to support the growing Internet of Things. Technologies associated with 5G are intended to speed up data even more while decreasing latency to a great level, providing massive network capacity, and improving reliability for fast and more secure connection, and maintaining consistency and performance also give high data rates. While this generation is relatively new but works 30 times faster than 4G and is more flexible in the network, it is intended to provide a more unified experience for all.

Table 2.1: Timeline of Wireless Communication Technologies

Generations	1G	2G	3G	4G	5G
	1980	1990	2000	2010	2020
Кеу	Voice	Data Mobility	High speed data	Data rates increased.	Ultra-low
Features	Mobility.	and	and voice capacity	Uses Internet	latency,
		voice capacity	added.	protocol.	High
		added.			throughput,
					increased
					spectrum
					efficiency,
					traffic capacity
					and
					connection
					density,
					massive
					network
					efficiency.
Services	Analogue	Digital voice	Mobile broadband.	Fast mobile	Mission Critical
	voice calls	calls.	(Email <i>,</i>	broadband	Control
		Texting	Web Browsing,	(Multiplayer games,	Services,
			Music/Video	mobile commerce,	Enhanced
			downloads,	Machine 2 Machine,	mobile
			Navigation,	Mobile Networking,	broadband,
			Location Services,	Multimedia,	Massive
			Application)	Broadcast/Multicast)	Internet of
					Things

2.2 Overview of Spread Spectrum

2.2.1 Spread Spectrum

Spread spectrum communication is a digital communication technology which uses fast codes

that run many times than information bandwidth or data rate [13]. One form of spread

spectrum multiple access communication is Code Division Multiple Access (CDMA). The

characteristics of spread spectrum signals is that their bandwidth is much greater than the information rate. The high levels of interference that are present in the digital transmission of information over some radio channels can be overcome by using a larger bandwidth than the minimum required [14]. The design of spread spectrum signal incorporates an element of pseudo randomness which makes the signals appear like random noise which makes the message difficult to decode and only the intended receivers are allowed to demodulate the signal [14]. In multiple-access communication systems, several users share a common channel bandwidth. Interference may occur as any user may transmit information simultaneously over the channel to the corresponding receivers [14]. If the users all use the same code for the encoding and decoding of the information, then each signal being transmitted may be differentiated by superimposing a different pseudo-random code, known as a PN sequence, onto each one [14]. Hence the message privacy is secured by recovering the transmitted information in the receiver by knowing the PN sequence. This is the communication technique used by CDMA. The advantages and disadvantages of spread spectrum is explained below:

Spread spectrum advantages:

- (1) Interference rejection is good.
- (2) Output signals have low power spectral density.
- (3) Inherent message is secured, and privacy is maintained.
- (4) The range of resolution is high.

Spread spectrum disadvantages:

- (1) The complexity of the system is high.
- (2) Frequency allocation is more difficult.

Spread spectrum techniques are divided into four basic types:

- (1) Direct sequence (DS) modulation
- (2) Frequency hopping (FH) modulation.
- (3) Pulse-FM or Chirp modulation
- (4) Time hopping

2.2.2 DS-CDMA Communication System

All users in Code Division Multiple Access (CDMA) systems send their signals simultaneously within the same bandwidth using a spread spectrum technique. In this transmission technique, the frequency spectrum of a data-signal is expanded by using an uncorrelated code. Therefore, the bandwidth occupancy becomes significantly greater than what is necessary. The spreading codes employed in this method possess low cross-correlation values and are exclusive to each user. This characteristic is the primary reason why a receiver can isolate the intended signal if it has knowledge of the corresponding transmitter's code.

Direct sequence signals are generated by modulating a carrier with a code sequence. In a DS-CDMA communication system the incoming information signal is digitized, and modulo-2 added to a higher speed code sequence [15]. Then the combined information and code are used to modulate using BPSK modulation technique [15]. Since the modulating function is dominated by high-speed code sequence that determines the radio frequency (RF) signal bandwidth and gives rise to the spread spectrum signal [15].

In the transmitter, the spreading sequence multiplies with the original narrowband. This signature comprises of a pseudo-noise like (PN) sequence that operates at a much higher chip than that of the user's symbol rate. A period of the PN sequence is exactly as long as one bit or symbol of the data sequence.

In the receiver the spreading sequence again multiplies with the received signal to break down the spectrum. If the reference signature of the receiver is synchronized to the data modulated PN sequence in the received signal, the original signal can be recovered.

A brief overview of the operation of Direct Sequence Spread Spectrum is detailed in Figure 2.1.



Spreading Code

FIGURE 2.1: Formation of Spread Spectrum Signal

2.2.3 Processing Gain

The ratio of the chipping frequency to the data frequency is equal to the processing gain.

There are two benefits acquired from high processing gain:

- Processing gain (Gp) is directly proportional to the ability of the system to reject interference which is called Interference rejection [13].
- Processing gain (Gp) is directly proportional to the capacity of the system which is called System capacity [13].

2.2.4 PN Code Generator

It generates a pseudo-random noise (PN) code sequence that is used to spread the encoded and modulated source data [13]. The performances of the system using various PN sequences with different correlation properties are compared among them. The PN sequences used are msequences and Walsh sequences.

There are Pseudo – random code properties [13]:

- 1- It must appear random.
- 2. It must be deterministic.
- 3. The code must have a long period.
- 4. Between any two codes the cross-correlation must be less.

2.3 Binary Phase Shift Keying (BPSK)

2.3.1 Simulation Method

BPSK is a modulation technique where the message bits used Non-Return to Zero (NRZ) coding, and it has two different phases 0 and π . The BPSK transmitter is added with the Additive White Gaussian Noise in the channel where the spectrum of the noise is flat for all frequencies which follows the Gaussian distribution function. In the receiver section, the distorted signal due to noise is received, not the pure message signal. Then the received signal with the transmitted signal is compared to calculate the number of errors to get the bit error rate. Hence, the simulation and the theoretical result are differentiated.



FIGURE 2.2: Block diagram of BPSK transmitter-receiver

The MATLAB consists of six script files which have got five auxiliary functions and one main function. First, some random binary bits '0' and '1' are generated for the message signal. Then the BPSK message bits are converted to the symbol by shifting '0' to '-1' and '1' to '1' on the transmitter side. Next, the Additive White Gaussian Noise is added to the channel and its value is calculated by taking the value of bit energy 1 and by varying the sigma square to (1/SNR). In the receiver section, the received signal of the originally transmitted signal and the noise is received. There are two decision regions forming a boundary of the threshold at 0. It defines that if the received signal is greater than zero then symbol '1' was transmitted which means message bit '1' and if the received signal is less than zero then it decodes that the symbol was '-1' which has got message bit '0'. In this way, the original message signal is reconstructed. Then coherent detection method is used by comparing the transmitted signal with the reconstructed signal and hence the bit error rate for the simulation of BPSK is calculated by the number of incorrect bits divided by the total number of bits. In the main function, the number of bits, Signal to Noise ratio (SNR), BER of simulation, BER of theoretical value are initialized and invoke the five functions. Thus, the curve of BER versus SNR in dB is plotted and collates the theoretical result with the simulated result.

Bit Error Rate verses SNRdB for BPSK modulation 10⁰ theoretical simulation 10⁻¹ 10⁻² 10⁻³ 업 비원 10⁻⁴ 10⁻⁵ 10⁻⁶ 10⁻⁷ 10⁻⁸ 2 4 6 8 10 12 SNR(dB)

2.3.2 Simulation Results

FIGURE 2.3: BER versus SNR (dB) of BPSK

From figure 2.3 it is seen that the simulated curve almost converges with the theoretical curve. For example-at 6 dB of SNR, the simulated BER value is 0.0022 and the theoretical BER value is 0.0024, which concludes the difference is very small.

2.4 Quadrature Phase Shift Keying (QPSK)

2.4.1 Simulation Method

QPSK is a phase modulation scheme that has two components In-phase and Quadrature phase [b]. QPSK is a combination of two BPSK signal and it has four different phases each differed by 90°(0°,90°, 180°, 270°) to represent the message signal. The QPSK encodes four symbols which mean 2bits/symbol. Then the transmitted signal is added to the AWGN channel. Like BPSK, the receiver demodulates the QPSK symbol based on its position in the signal space diagram determined by the four decision regions.



FIGURE 2.4: Block diagram of QPSK modulator



FIGURE 2.5: Block diagram of QPSK demodulator

The MATLAB code simulates the QPSK signal consisting of six script files which has got five auxiliary functions and one main function. Initially, some random blocks of bits '0' and '1' are generated for the QPSK signal. The message bits are converted to the symbol by taking the real value of both the In-phase and Quadrature phase value '0' to '-1' and '1' to '1' on the transmitter side. Next, the Additive White Gaussian Noise is added to the channel where the value of M is 4 and noise variance is varied with SNR in linear scale and has taken log₂(M) into account and thus noise is calculated. In the receiver section, the received signal is achieved by adding the transmitted signal and the noise. Then the detection process is done by setting four decision regions. If the received signal lies in the region of $\geq 0^\circ$ and $\leq 45^\circ$ and $\geq 135^\circ$ then the assumption is made that the message bit is 00, if the decision region is $> 45^\circ$ and $\leq 135^\circ$ then the message bit is 10. In this way, the message signal is reconstructed and concatenates the reconstructed message bit separately. Then coherent detection method is used by comparing

the message bits with the reconstructed message bits and consequently, to determine the bit error rate in a QPSK simulation, the number of errors is counted and divided by the total number of bits. In the main function, the initialization is done by taking the number of bits to 1000, the range of Signal to Noise ratio (SNR)(dB) is taken from 0 to 15, BER of simulation, BER of theoretical value is set to zero and invoke the five functions. Hence, achieved the curve of BER versus SNR in dB by contrasting the theoretical result with the simulated result.
2.4.2 Simulation Results



FIGURE 2.6: BER versus SNR (dB) of QPSK

From figure 2.6 the simulated curve coincides with the theoretical curve. It is observed that with the increasing SNR (dB) the value of BER is decreasing. For example-at 5 dB of SNR, the simulated BER value is 0.006 and the theoretical BER value is 0.0059, which implies the error is very small. Therefore, the QPSK has a higher data rate and gives similar BER performance.

2.5 Asynchronous Code Division Multiple Access (CDMA)

2.5.1 Simulation Method

DSSS for CDMA was a widely used multiple access technique for 3G networks in mobile communication systems. In comparison to FDMA and TDMA, CDMA provides higher network capacity as every user transmits at the same frequency and time because each user has unique codewords as spreading code which is orthogonal to all other user's spreading code. In the DSSS CDMA, the user data is multiplied with the high bandwidth unique spreading code which uses pseudorandom numbers whose autocorrelation have properties that resemble white noise. An AWGN channel is added to the transmitted spreading signal in the receiver. The receiver uses the correlation properties to retrieve the original signal by multiplying the received signal with the same synchronized code used in the transmitted signal by removing the code. Then the BER of DSSS CDMA is computed and from the graph, the performance is observed.



FIGURE 2.7: CDMA transmitter



FIGURE 2.8: CDMA receiver

The MATLAB code simulates the DSSS Asynchronous CDMA which consists of nine script files. Initially, some random blocks of bits '0' and '1' are generated for CDMA for four transmitter signals and the length of the bit is calculated. The conversion of message bits to the symbol is from '0' to '-1' and '1' to '1' on the transmitter side and each bit is generated for twenty samples long and the length of the bit sequence is measured. Then the pseudorandom bits are generated for each bit with processing gain twenty, different for each channel and successive connection. The pseudorandom bits are mapped to '0' to '-1' and '1' to '1', after that the bit sequence is multiplied by the pseudorandom sequence to get the transmitted spreading signal. These steps are repeated for all four users by spreading the signal with spread code. Next, in the channel section, the Additive White Gaussian Noise is added where the average bit energy taken is 1, the square root of processing gain is multiplied with the noise variance and the random noise to get the value of noise. In the receiver section, the spreading signal of user 1 is added with the noise to get the composite signal then applied user 1 code with the composite signal and take the decision for every bit by multiplying the received signal for 20 samples with the spreading code and sum them up and divide by the processing gain, if it comes > 1 then the reconstructed bit 1 otherwise 0 is received. This process is repeated a total of four times,

but the received signal is applied with the user 1 spreading signal to recover the original data. Then coherent detection method is used by comparing the message bits with the reconstructed message bits and hence the bit error rate for the simulation of Asynchronous CDMA is computed by counting the number of errors divided by the length of the bits. In the main function, the initialization is made by taking the number of bits to 100000, the range of Signal to Noise ratio (SNR)(dB) is taken from 1 to 20, processing gain is 20, BER of simulation for all four users, BER of theoretical value is set to zero and invoke the eight functions into the main function. Lastly, the graph of message signal, pseudorandom signal, spread spectrum signal, despreading signal, BER simulation of all four users, theoretical BER versus SNR in dB is plotted. Thus, the theoretical and the simulated result are compared for analysis.

System Parameters	Value
Number of bits	100000
Processing gain	20
SNR	1 to 20
Number of users	1,2,3,4

Table 2.2: Parameter of the System Model

2.5.2 Simulation Results



FIGURE 2.9: BER versus SNR (dB) of Asynchronous CDMA

From figure 2.9 it is observed that in asynchronous CDMA the curves will go upward and flatten as the different users agree on half code and disagree on the other half for which the crosscorrelation is similar and causing interference in the system, so more interference when there is more user in the receiver. For example-at 9 dB of SNR, the simulation value of BER for user 1,2,3,4 is 3×10^{-5} , 0.0013,0.0063,0.0148 and the theoretical value of BER is 3.36×10^{-5} , which implies the error gets bigger. Also, we see that with the increasing processing gain the bandwidth increases which is costly and creates complexity for the hardware.

2.6 Synchronous Code Division Multiple Access (CDMA)

2.6.1 Simulation Method

Synchronous CDMA offers an advantage of using the spectrum more efficiently by providing flexible resources in the allocated place in the mobile telecommunication. This technique is widely used on the downlink from base station to a mobile unit. It is a technique where each user sends information independently over the AWGN channel using Walsh code which generates the Hadamard matrix. Hadamard code uses orthogonal property which means it is a linear orthogonal error-correcting code and it has good autocorrelation and bad cross-correlation. The time delays are arbitrary for each user as they arrive at the receiver asynchronously. Therefore, the receiver reconstructs the signal with very low interference or without mutual interference as they have low cross-correlation. Then the BER is computed by juxtaposing the theoretical and simulated result.

The MATLAB code simulates the Synchronous CDMA which consists of nine script files. Initially, in the main function, the number of bits to 1000,000 is set, the number of users to 4 which is also the processing gain, generated the Hadamard code for 4 users by using the inbuilt function of MATLAB, the range of Signal to Noise ratio (SNR)(dB) is taken from 1 to 20 dB, BER of simulation for all four users, BER of theoretical value are set to zero. Then some random blocks of bits '0' and '1' are generated for CDMA for four transmitted signals and their length is calculated in a different function. Next, for user 1, the data bits to the symbol from '0' to '-1' and '1' to '1' is converted on the transmitter side. Then multiplied the bit sequence with the 1st

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row of Hadamard code to get the spreading sequence. These steps are repeated for all four users by spreading the signal with the consecutive row of Hadamard code. Then the noise is measured in the AWGN channel where the average bit energy is taken 1, the square root of processing gain which is the user number is multiplied with the noise variance and the random noise. In the receiver section, the spreading signal of all four users is added with the noise to get the composite signal. Then to recover the user 1 code multiplied the received signal with the 1st row of Hadamard code for despreading the code and transpose this signal and set the decision region to this signal > 0 then the restored signal is 1 otherwise 0. This process has repeated a total of four times for four users each time decoding the received signal with the consecutive codes of Hadamard. Then compared the transmitted signal with the demodulated signal to get the error and the BER is calculated from the error divided by the length of the bit. In the main function, invoked these eight functions. Ultimately, plotted the graph of BER simulation of all four users, theoretical BER versus SNR in dB.

Tab	le	2.3:	Parameter	of	the	Sy	/stem	Mod	el	
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System Parameters	Value
Number of bits	1000000
Processing gain	4
SNR	1 to 20
Number of users	4

2.6.2 Simulation Results



FIGURE 2.10: BER versus SNR (dB) of Synchronous CDMA

From figure 2.10 it is observed that in synchronous CDMA the curves coincide with the theoretical curve and with the increasing user some points of the simulated curve will go downward. This implies that the curves for the different users will go down as the interference will be less and some interference might not have any impact. For example-at 9 dB of SNR, the simulation value of BER for user 1,2,3,4 is 3.5×10^{-5} , 2.8×10^{-5} , 2.9×10^{-5} , 3.1×10^{-5} and the theoretical value of BER is 3.36×10^{-5} , which implies the error is very small.

Chapter 3

Performance Analysis of Asynchronous CDMA Systems with disparate power levels

3.1 Multiple Access Detection for Asynchronous CDMA

3.1.1 Multiple Access detection using correlation receiver

In conventional CDMA, each user is considered as the signal whereas the other users are treated as the interference whether as Multiple Access Interference (MAI) or noise [2]. The interference suppression capability is measured by the processing gain where the detection of the desired signals is protected against the interference due to the other users [2]. The performance degradation of the noise decreases as the number of interference users increases hence the bit error rate (BER) increases. Therefore, all users interfere with all other users, so the interference causes performance degradation. There exist receivers that employ multiuser detection, where all users are considered as signals for each other. While this approach can result in performance improvement, it also results in substantially increased complexity [14]. This thesis considers the sub-optimal but widely used correlation receiver for multiple access reception.

In cellular systems, numerous mobiles communicate with one Base station (BS) and the BS has information regarding the pseudorandom sequence of all mobile also must detect all the signal, but mobiles only are concerned about their signals [14]. Thus, at the BS or in uplink multiple access detection is mainly directed [14].



FIGURE 3.1: Block diagram of a multiple access Ds CDMA system

3.1.2 Simulation Method and Results

First, consider the different processing gains for one user in an Asynchronous CDMA system. Generate some random blocks of bits for our transmitted signal then do the conversion of message bits to symbols and each bit is generated for a particular processing gain. The pseudorandom sequence is generated for each bit with their corresponding processing gain. The pseudorandom sequence is multiplied by the bit sequence and mapped to get the desired transmitted signal. In the channel section, the Additive White Gaussian Noise is added with the average bit energy 1, the square root of processing gain is multiplied with the noise variance and the random noise to get the value of noise. In the receiver section, add the spreading signal of user 1 with the noise to get the composite signal then apply user 1 code with the composite signal and take the decision for every bit by multiplying the received signal for corresponding processing gain with the spreading code and sum them up and divide by the processing gain, if it comes > 1 then get the reconstructed bit 1 otherwise 0. Then the message bits are compared with the reconstructed message bits and hence the bit error rate is computed by counting the number of errors divided by the length of the bits. Initialize the number of bits to 100000, the Signal to Noise ratio (SNR) range in dB is 1 to 10, the BER simulation values to zero for one user, diversified chips per bit (processing gain) are taken 1,2,4,8,16 in the main function. Five functions are taken in a loop for various chips per bit as explained. Then, plot the graph of bit error rate versus SNR range for different processing gains. The simulated results are compared for analysis.

Table 3.1: Parameter	of the S	ystem Model
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System Parameters	Value
Number of bits	100000
Processing gain	1,2,4,8,16
SNR	1 to 10 dB
Number of users	1



FIGURE 3.2a: BER versus SNR (dB) as parameterized by the number of users (N=1) of Asynchronous CDMA systems for different processing gain

From figure 3.2a it is observed that in asynchronous CDMA for different processing gain such as-chips per bit=1,2,4,8,16 for one user the curves will go downward. We see that all the curves are roughly the same for different processing gains which shows that the interference is less, and some interference might not have any impact as the curves are overlapping with each other.

Next, consider four users in the Asynchronous CDMA system for different processing gains. Here generate some random blocks of bits for four transmitted signals, do the conversion of message bits to symbol, and each bit is generated for specific processing gain. The pseudorandom sequence is generated for each bit with their corresponding processing gain, different for each channel and successive connection. The pseudorandom sequence is multiplied by the bit sequence and mapped to get the required transmitted signal. These steps are repeated for four users. Next, in the channel section, the Additive White Gaussian Noise is added with the average bit energy 1, the square root of processing gain is multiplied with the noise variance and the random noise to get the value of noise. In the receiver section, add the spreading signal of user 1 with the noise to get the composite signal then we apply user 1 code with the composite signal and take the decision for every bit by multiplying the received signal for desired processing gain with the spreading code and sum them up and divide by the processing gain, if it comes > 1 then we get the reconstruct bit 1 otherwise 0. This process is repeated for four users, but the received signal is applied with the user 1 spreading signal to recover the original data. Then the message bits are compared with the reconstructed message bits and hence the bit error rate is computed by counting the number of errors divided by the length of the bits. Initialize the number of bits to 100000, the number of users taken 4, all the BER simulation values to zero for four users, the Signal to Noise ratio (SNR) in dB is 8, chips per bit (processing gain) is varied and values are considered 8,16,32,64 in the main function. All the eight functions are taken in a loop for various chips per bit as explained. Then, we plot the graph of bit error rate versus the number of users for all four users. Then explore the different values of processing gain and checked how many users could be supported with high background SNR ratio. The simulated results are compared for analysis.

Table 3.2: Parameter of the System Model

System Parameters	Value
Number of bits	100000
Processing gain	8,16,32,64
SNR	8 dB
Number of users	1,2,3,4



FIGURE 3.2b: BER versus krange as parameterized by the number of users (N=1,2,3 and 4) of Asynchronous CDMA systems for different processing gain

From figure 3.2b it is observed that in asynchronous CDMA for different processing gain such as-chips per bit=8,16,32,64 for four users the curves will go upward. It is seen that with the higher number of users the bit error rate increases with the different processing gain. For example- for 2 and 4 users for processing gain 8,16,32,64 the BER values are 0.01283,0.00379,0.00116 and 0.00044 comparatively to 0.06975,0.02684,0.0079 and 0.00242. Thus, the higher BER value with more users is an indicator of poor performance also the strongest signal with less processing gain has the minimum MAI and the weakest signal with the more processing gain has the maximum MAI.

3.2 Bandpass Signal for Asynchronous CDMA

3.2.1 Bandpass Signal

The multi-carrier DS CDMA system is proposed by which a data sequence and a spreading sequence is multiplied to modulate M carriers rather than a single carrier [16]. "The receiver provides a correlator for each carrier and the outputs of correlators are combined with a maximal ratio combiner" [16]. The technique where each of the M sequences assigned to an individual user is distinct and each user has a unique set of spreading sequences and so each user in a spreading sequence is different has some desirable features that include narrowband interference suppression and lower chip rate required to achieve the same bandwidth needed for the single carrier system [17]. This implies that the number of carriers is equal to the processing gain and a narrow band waveform is conveyed by each carrier [16]. It supports more users for a fixed probability of error and the autocorrelation side lobes are canceled thus the data rates are increased [17].

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Any Bandpass signal is represented in terms of magnitude and phase distortion, In-phase(I) and Quadrature(Q) notation, and complex exponential form. Here, user, k is 3 and has three signals s1(t), s2(t), s3(t) where s1(t) is the desired signal. For each signal $s_i(t)=\sqrt{2P} \times a_i(t) \times cos (2 \times \pi \times f_c$ $\times t+$ theta (i)) where P is the signal power, $a_i(t)$ is the spreading code for the ith user, f_c is the carrier frequency and theta(i) are the phase of the ith signal which is between 0 to 2π . Theoretically the bandpass signals can be represented as $s_i(t) = Re \{s_i(t) \times B(t) \times e^{-1}(-j \times 2 \times \pi \times f_c \times t)\}$ where $s_i(t) \times B(t)$ is the complex baseband portion of the signal. This baseband signal can be broken down into In-phase(I) and Quadrature phase(Q) components.

In-phase: s_i(t)_I(t)=Re {s_i(t) ×B(t)},

Quadrature: s_i(t)_Q(t)=Im{s_i(t) ×B(t)}

In the synchronous case where all the interference signals are aligned in phase and timing with the desired signal and different processing gains will have an impact on the different number of users. In most cases, the interferers are located at different locations of the network, and it's not possible to synchronize all the users which refer to different timing and phase in the uplink. Here we will consider different phases for different users. For example, 3 different users are located at different places and can't coordinate the exact time and phase for which the interferers are received out of phase and modeled as theta(i) as their random phase of the signal and distributed between 0 to 2π . The receiver is synchronized to user 1 and has a theta value 0, but all other theta value is random with respect to that as each user has their own spreading code and carrier frequency. The bandpass signal has a given spectrum centered about f_c just like the Fourier transform. Then simulate the baseband signal which contains all information, and the spectrum is twice as the bandpass signal. The complex envelope of the bandpass signal is split into two components, namely the in-phase (0°) and quadrature-phase (90°) components. When the interferer is aligned with the desired signal at (0°), it can cause signal distortion, but if it is generated at (90°) relative to the desired signal, then it will have no effect on the receiver's performance. Therefore, the signal will be partially in phase and out of phase based on the random phase that is generated, and all in-phase and quadrature-phase are added together separately, and the final decisions are made on this variable for instance**r=rl×cos(theta(i)) + rQ×sin(theta(i))**. The BER will be slightly better for this case compared to asynchronous CDMA as the interference is partly out of phase and not full magnitude is hitting the desired signal to cause errors.







FIGURE 3.3: Block diagram of Baseband Signal of Asynchronous CDMA for Transmitter (User 1), Channel and Receiver (User 1)

3.2.2 Simulation Method and Results for multiple access detection

In the simulation, the data bits are generated for four users. The BPSK modulation is used, and the spreading sequence of the in-phase and quadrature-phase is produced for random phase, theta which is varied between 0 to 2π , and the transmitted signal for user 1 is considered as the desired signal who's in phase theta value is 0 whereas the other signals are the interfering signals with random carrier phase. In the AWGN channel, the noise will have identical statistics but will be created independently for in-phase and quadrature-phase components. In the receiver section, the in-phase and quadrature-phase of the transmitted signal are added separately with their corresponding noise in-phase(I) and quadrature-phase(Q) components. Then this individual I and Q components of the receiver is despread with respect to transmitted signal 1 after that added or subtracted together the I and Q component to get the final decision variable for each receiving signal. Next, the decision is made for every bit and the BER is computed. The number of bits taken 100000, power is same which is 1, processing gain is 20, SNR range is 1 to 20 and the plotting of BER simulation against the SNR range is done to analyze the performance.

System Parameters	Value
Number of bits	100000
Processing gain	20
SNR	1 to 20 dB
Number of users	1,2,3,4
Modulation	BPSK

Table 3.3: Parameter of the System Model



FIGURE 3.4a: BER versus SNR (dB) as parameterized by the number of users (N=1,2,3) of Asynchronous CDMA systems for Baseband Signal

From figure 3.4a it is observed that in the baseband signal of asynchronous CDMA for 3 users the BER value is better as the interference is less for which the curve goes downward. From the curve, it is seen that when SNR is 5 dB the BER is 0.00629,0.01026 and 0.01512 for user 1,2,3 which proves a good performance for the baseband signal.



FIGURE 3.4b: BER versus SNR (dB) as parameterized by the number of users (N=1,2,3 and 4) of Asynchronous CDMA systems for Baseband Signal

From figure 3.4b it is observed that in the baseband signal of asynchronous CDMA for 4 users the BER value is less as the interference is less for which the curve goes downward. From the curve, it is seen that when SNR is 9 dB the BER is 5×10^{-5} , 0.00036,0.00183 and 0.00433 for user 1,2,3,4 which proves BER flattens out by giving better performance for the baseband signal comparatively to the asynchronous CDMA as not all the interference is in the same direction some are out of phase also causing minimum errors.

3.2.3 Simulation Method and Results for multiple access using correlation receiver of different processing gain

Next, consider the baseband signal of asynchronous CDMA for different processing gains for four users. The multiple access detection strategy brings information about multiple users which is used to better detect individual users for interference cancellation. The utilization of multiple access detection has the potential to provide significant additional benefits.

Here, the random data bits are generated for four users. The spreading sequence of the inphase and quadrature-phase is created for random phase, theta which is varied between 0 to 2π , and the transmitted signal for user 1 is considered as the desired signal who's in phase theta value is 0 whereas the other signals are the interfering signals with random carrier phase. In the AWGN channel, the noise is independently produced for in-phase and quadrature-phase components. In the receiver section, the in-phase and quadrature-phase of the transmitted signal are added separately with their corresponding noise in-phase(I) and quadrature-phase(Q) components. Then this individual I and Q components of the receiver is despread with respect to transmitted signal 1 after that added or subtracted together the I and Q component to get the final decision variable for each receiving signal. Next, the decision is made for every bit and the BER is calculated. The number of bits taken 100000, power is taken same which is 1, number of users is 4, initialize all the BER simulation values to zero for four users, the Signal to Noise ratio (SNR) in dB is 8, processing gain is varied, and values are considered 8,16,32,64, and the plotting of BER simulation against the number of users is done to analyze the performance.

Table 3.4: Parameter of the System Model

System Parameters	Value
Number of bits	100000
Processing gain	8,16,32,64
SNR	8 dB
Number of users	1,2,3,4



FIGURE 3.5: BER versus krange as parameterized by the number of users (N=1,2,3 and 4) of Asynchronous CDMA systems of Baseband Signal for different processing gain

It is observed that the baseband signal of asynchronous CDMA for different processing gains for 4 users the BER value is high as the number of users is more for which the curve goes upward.

From the curve, it is seen that for 4 number users the BER for processing gain 8,16,32,64 is 0.03092,0.0092,0.00285 and 0.00115 which indicates the performance is poor and the values of BER is decreasing. After adding more users to the system, the interference itself causes errors for which the performance degrades thus the difference in BER employing different spreading sequences is smaller.

3.3 Near Far Effect on Asynchronous CDMA

3.3.1 Near Far Effect

The Near Far problem occurs due to the sharing of the same channel by many users that is if the interfering signal is strong compared to the desired signal, then its contribution to the total received signal will make the reliable reception of the desired signal difficult [13]. Here we are considering the receivers are not centralized in one location and the powers cannot be equal in all cases but considering the case where there is different channel model, and the wireless channel interacts and causes one user to be stronger and weaker than others. For instance, the strong signal received from the mobile user close to a base station will overwhelm the weak signal from a mobile user far from the base station. Therefore, as the number of users increases the interference also increases and a stronger interferer act like the power degrade much more rapidly with interference, and when interferer is weaker the performance gets much closer to the desired signal at all. This poses a difficulty to the detector in making reliable decisions.

3.3.2 Power Control and Solution

Power Control is one of the solutions to alleviate the near-far problem by adapting the power of each transmitter to change in the channel response or the interference environment. Power control works in a centralized manner in the uplink which attempts to receive a constant average power for each user reaching the base station irrespective of the distance from the base station. Hence it decreases the co-channel interference and increases the system capacity as the performance of the transmitter power is one of the dependent factors [13]. Suppose when the mobile user moves close to the base station it reduces the power level to reduce the interference of other users and vice versa. Therefore, the power control can be implemented by varying the mobile transmitted power such that at the receiver the sufficient SIR is maintained for each transmission [14]. Thus, if the power control is adjusted then the maximum capacity can be accomplished as for the acceptable error rate the exact SIR is achieved [14].

3.3.3 Simulation Method and Results

Consider two scenarios of the near-far effect for multiple users.

First, consider two users in the Asynchronous CDMA system. Here the amplitude of desired user signal is held constant, and the amplitude of the other user is varied, and the power domain is 2,4,10,1/10 times more powerful than the desired signal. So, when the amplitude of the desired signal is 1 and the amplitude of user 2 is $\sqrt{2}$ then the ratio of power for user 1 and user 2 is 3dB. Then when the amplitude of user 2 is changed to $\sqrt{4}$ and $\sqrt{10}$ then the ratio of the power for 2 users is 6 and 10dB which is evident as there is the difference in signal powers.

The last case is when the power of user 2 is 10 times less to user 1 i.e., 1/10 and the amplitude is $\sqrt{1/10}$ then the power of the second user is -10dB. This simulated the detecting of the wanted signal when it is both far (-10dB) and near (+10dB). The simulation is done for 100000 bits for two users of processing gain 30 in AWGN channel and the power factor and the amplitude are calculated and considered as described above. The simulation results are shown below.

System Parameters	Value
Number of bits	100000
Processing gain	30
Power ratio	3,6,10, -10
Number of users	1,2,3,4

Table 3.5: Parameter of the System Model



FIGURE 3.6a: BER versus SNR (dB) as parameterized by the number of users (N=1,2) of Asynchronous CDMA systems of Near Far Effect

From figure 3.6a it is observed that in asynchronous CDMA the curves will go upward and flatten for the different amplitude and different power for two users. It is seen that when the amplitude increases then the power also increases for the interference signal comparatively to the desired signal. And when the power of the interfering signal is -10dB it represents a weaker signal which is evident from the figure that this interfering signal and the desired signal are almost the same which shows very low power interference. On the contrary when the power is more for the second user then the interference is stronger and BER is rising. Hence it implies that with unequal power the system performance degrades as it causes increased MAI at the

detector. Thus, it shows the receiver has trouble in detecting the weak wanted signals when a strong interfering signal is nearby and exceeds the spreading gain of the users in the system [18].

Next, consider four users in the Asynchronous CDMA system. Here the amplitude of desired user signal is stable, and the amplitude of the other user is varied, and the power domain is 2,4 and 10 times more powerful than the desired signal. So, when the amplitude of the desired signal is 1 and the amplitude of the user 2,3,4 is $\sqrt{2}$ then the ratio of power for four users is 3dB with different spreading sequences. Then when the amplitude of the other 3 users is changed to $\sqrt{4}$ and $\sqrt{10}$ then the ratio of the power for 4 users is 6 and 10dB which is evident as there is the difference in signal powers. The simulation is performed of detecting the wanted signal when it is (+3, +6, +10) dB for 100000 bits for four users of processing gain 30 in AWGN channel and the power factor and the amplitude are calculated and explained above. The simulation results are shown below.



FIGURE 3.6b: BER versus SNR (dB) as parameterized by the number of users (N=1,2,3 and 4) Asynchronous CDMA systems of Near Far Effect

From figure 3.6b it is observed that in asynchronous CDMA the curves will go upward and flatten for the different amplitude and different power for four users. It is evident that when the amplitude and the power increase, that is when the power gets 2,4 and 10 times more powerful, then the interference signal is stronger compared to the desired signal. And there

some signal is close to the other signal due to the different random sequence numbers and the power as well as the BER is rising. Thus, it shows the receiver has trouble in detecting the weak wanted signals when a strong interfering signal is nearby and exceeds the spreading gain of the users in the system. Therefore, the system performance decreases [1].

Chapter 4

Performance of Asynchronous CDMA Systems with Quantization

4.1 Quantization Process

4.1.1 Quantization Method

The act of mapping infinite, continuous values to a finite set of discrete values is referred to as quantization. When used in simulations, this involves the estimation of real-world values through digital representation, which introduces constraints on the range and precision of a value. The analog to digital converter works as a quantizer which follows the quantization process by undergoing the sampling and quantizing. Quantization is a process that involves representing the amplitude of sampled values with a finite set of levels. The discrete amplitudes produced by quantization are referred to as representation levels. The distance between two adjacent representation levels is called the step-size.

4.1.2 Simulation Results

The figure below depicts the process of quantizing an analog signal.



FIGURE 4.1: Analog to Digital Signal

There are two types of quantization, one is Uniform Quantization and another one is Non-Uniform Quantization. In Uniform Quantization the quantization levels are uniformly spaced, and it has two types. They are Mid-Rise type and Mid-Tread type. In this case, it has used the Mid Rise which has the origin lies in the middle of a raising part of the staircase. As illustrated in the figure above, the number of quantization levels in this type is an even quantity.

4.2 Effects of MMSE A/D conversion in Asynchronous CDMA Systems

4.2.1 System Model

Here, a CDMA System is considered which adopts Binary Phase Shift keying (BPSK) modulation on an Additive White Gaussian Noise (AWGN) Channel and Analog to Digital(A/D) Conversion is performed at the front end of the receiver [3]. The effects of A/D conversion on the overall system performance are investigated and modeled, considering both sampling and quantization [3]. The minimum mean squared error is the most popular criterion in this framework, intuitively connected to the maximum signal to noise ratio criterion mostly used for communication and detection applications [18]. The quantization-constrained estimators may have practical interest in low complexity applications that use A/D converters with limited number of bits, such as low power wireless sensor applications [18].

The simulations are performed in continuous real numbers but the impact of quantization at the front end of the receiver with the A/D converter will have finite amount of precision and that might be 2/4/6/8/10/12/16 bits but not unlimited. With one user will not be a huge difference but with multiple users, especially when one of the signals is stronger than the others will probably be a big determinant factor of the system. When the received signal is generated which is the addition of desired signal, interfering signal, and noise at each individual chip then for each sample of the receive signal it should look at quantizing nodes to several different levels to one of the finite number of levels that is precision. If there are 2 bits there are 4 different levels, if 4 bits of precision there will be 16 different levels, 8 bits of precision 256 different levels. The quantizer will figure out the range of the signal and divide the signal to get equal spacing over that interval for the step size. The actual system would perform some calculations to round off for getting the closest value of the signal by simplifying the receive signal level over the range and dividing it up by the levels for each individual chip to see the impact of ADC in the signal. The analysis for the performance of MMSE for single user receiver for uniform quantization in terms of different number of levels for asynchronous CDMA signals in AWGN channels is investigated which offers greatly improved capacity in terms of the achievable number of users in low mobility applications.

4.2.2 Simulation Method

First, CDMA is a spread spectrum technique which generates some random blocks of data, and each bit is produced for a specific processing gain like 8. The PAM signal is produced from a sequence of pseudorandom data and a spread signal modulated from a digital scheme like BPSK. The CDMA receiver demodulates the incoming signal that was added with the noise to recover the chip PAM sequence which is multiplied by the spreading signal used in the transmitter for despreading. Then the signal was quantized to 'b' bits and the signal is divided from 0 to 2ⁿ-1 levels and rounded down and the minimum mean square error is calculated for different number of bits such as 2,4,8,16. Then, the figure of quantized signal and the minimum mean square error (MMSE) versus SNR range for different number of bits is plotted. The simulated results are compared for analysis.

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4.2.3 Simulation Results



FIGURE 4.2a: Quantized Signal as a function of discrete time



FIGURE 4.2b: MMSE versus SNR (dB) as parameterized by the number of users (N=1) of Asynchronous CDMA systems for different number of bits

From the figures it is observed that as the number of quantization levels increase the quantization error reduces thereby the approximation of the results becomes accurate and therefore the performance of the system approaches that of unquantized. Decreasing the quantization error decreases the additive noise vector which in turn reduces the interference [19]. As the interference reduces the SIR increases which in turn reduces the BER [19].
4.3 Quantization on A/D receiver of Asynchronous CDMA Systems

4.3.1 System Model

In this system, k users are transmitting CDMA signals on an AWGN channel. In CDMA system, input data is directly modulated using PN sequences that the resulting signal has same bandwidth as the rate of the spreading sequence [19]. After modulation AWGN is added to the transmitted signal. In demodulation PN sequence is used to despread the signal so that the original data can be extracted. At the front end of the receiver, analog to digital converter is used for the quantization which uses midrise quantizer with even number of quantization levels for simulation. The ranges of the quantizers varies for multiple user's cases as the different signals act as multiple access interfering signals which are added with the transmitted signal and thermal noise and can be determined by minimizing the quantization error in a mean square sense. The ADC in this model has a variable input range, the number of bits is b, and the quantization step is uniform i.e., 1/2^b-1 as it has been assumed the quantization process is round off to the nearest quantization level whose step size is uniform. Due to the presence of gaussian noise at the input can reliably model the quantization noise as a uniform random variable of variance $(1/2^{b}-1)^{2}$ [20]. As sampling and quantization are the task to be carried out to digital receiver for DS-CDMA systems to ensure that input is within the operating range of the ADC the received signal must be properly scaled. This scaling affects the performance of the receiver since the power of the desired user's signal varies as the power of the MAI varies. The performance degradation of the correlation receiver due to the quantization effects is evaluated [4]. The number of quantization level will be more dramatic more interference

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signals are added rather than a single user which has no impact on just like without quantization. Therefore, the impact of quantization for CDMA system is observed for multiple users.





FIGURE 4.3: Block diagram of Asynchronous CDMA systems for quantization effect

4.3.2 Simulation Method and Results

Initially, generate some random blocks of bits for transmitted signal then do the conversion of message bits to symbols and each bit is generated for a particular processing gain. The pseudorandom sequence is generated for each bit with their corresponding processing gain. The pseudorandom sequence is multiplied by the bit sequence and mapped to get the desired transmitted signal. The channel section has the Additive White Gaussian Noise with the average bit energy 1, the square root of processing gain is multiplied with the noise variance and the random noise to get the value of noise. In the receiver section, add the spreading signal of user 1 with the noise and for user 2 case add the second transmitted signal along with it also to get the composite signal then apply user 1 code with the composite signal to get the despreading of the code. Then the despreaded signal is passed for the quantization process where the levels are between the maximum and minimum amplitude of the received signal with the difference of delta. Hence the quantized signals are achieved by using the default quantiz function and take the decision for every bit by multiplying the received signal for corresponding processing gain with the spreading code and sum them up and divide by the processing gain, if it comes > 1 then get the reconstructed bit 1 otherwise 0. Then the message bits are compared with the reconstructed message bits and hence the bit error rate is computed by counting the number of errors divided by the length of the bits for the different number of users for different bits. Repeat this whole process for 100000 times the number of bits taken is 1,2,4,8 for 2 users the Signal to Noise ratio (SNR) range in dB is 1 to 10, the processing gain is 8, initialize the BER simulation values to zero for all users. Then, plot the graph of bit error rate versus SNR range for quantization of 2 users. The simulated results are compared for analysis.

Table 4.1: Parameter of the System Model

System Parameters	Value
Number of message bits	100000
Number of quantization bits	1,2,4,8
Processing gain	8
SNR	1 to 10 dB
Number of users	1,2



FIGURE 4.4a: BER versus SNR (dB) as parameterized by the number of users (N=1,2) of Asynchronous CDMA systems for quantization effect

It has been analyzed from the figures that the correlation receiver is near far resistant when the number of bits/samples is sufficiently large however there is significant degradation in performance when the number of bits/samples is small, and this performance degradation becomes larger as the number of users increases [4]. We observe that for asynchronous CDMA systems the quantization effect for more users degrades than for a smaller number of users. The BER for user two is less than for user one but with the increasing number of bits the

performance is better. For example, at 6dB the BER is 0.00231 for one user and for user two it is 0.02257 which shows that for user 1 having 8 bit gives a better performance.

Next, generate some random blocks of bits for transmitted signal then do the conversion of message bits to symbols and each bit is generated for a particular processing gain. The pseudorandom sequence is generated for each bit with their corresponding processing gain. The pseudorandom sequence is multiplied by the bit sequence and mapped to get the desired transmitted signal. The channel has the Additive White Gaussian Noise with the average bit energy 1, the square root of processing gain is multiplied with the noise variance and the random noise to get the value of noise. In the receiver section, add the spreading signal of user 1 with the noise and for user 2,3,4 case add the prior transmitted signal along with it as it acts as the interference signal to get the composite signal then apply user 1 code with the composite signal to get the despreading of the code. Then the despreaded signal is passed for the quantization process where the levels are between the maximum and minimum amplitude of the received signal with the difference of delta and the range varies for different users. Hence the quantized signals are achieved by using the default quantiz function and take the decision for every bit by multiplying the received signal for corresponding processing gain with the spreading code and sum them up and divide by the processing gain, if it comes > 1 then get the reconstructed bit 1 otherwise 0. Then the message bits are compared with the reconstructed message bits and hence the bit error rate is computed by counting the number of errors divided by the length of the bits for the different number of users for different bits. Repeat this whole process 100000 times, the number of bits taken is 1,2,4,8 for 4 users the

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Signal to Noise ratio (SNR) range in dB is 1 to 15, the processing gain is 15, initialize the BER simulation values to zero for all users. Then, plot the graph of bit error rate versus SNR range for quantization of 4 users. The simulated results are compared for analysis.

Table 4.2: Parameter of the System Model

System Parameters	Value
Number of message bits	100000
Number of quantization bits	1,2,4,8
Processing gain	15
SNR	1 to 15 dB
Number of users	1,2,3,4



FIGURE 4.4b: BER versus SNR (dB) as parameterized by the number of users (N=1,2,3,4) of Asynchronous CDMA systems for quantization effect

From the figure it is analyzed that the correlation receiver is near far resistant when the number of bits/samples is sufficiently large however there is significant degradation in performance when the number of bits/samples is small, and this performance degradation becomes larger as the number of users increases [4]. It is observed that for asynchronous CDMA systems the quantization effect for more users degrades than for a smaller number of users. The BER for user 4<3<2<1 but with the increasing number of bits 1<2<4<8 the

performance is better. For example, at 5 dB the BER for user 1,2,3,4 is 0.00704, 0.01947, 0.03456 and 0.04907 which shows that for user 1 having 8 bits gives a better performance than user 2,3 and 4.

4.4 Near Far Effect of Quantization on Asynchronous CDMA Systems

4.4.1 System Model

The Near Far effect of quantization for Asynchronous CDMA system is evaluated for different power levels, different number of bits. The digital signal processor does not work with real valued numbers it works with the digital representation of the numbers which is good but gives worst performance compared to real valued numbers and that's more efficient to work with the quantized signal. A high-level, high-resolution ADC is difficult to design and extremely power hungry. The minimum ADC resolution required can be obtained from two methods. One is the assumption that the quantization noise dominates over all the sources which has a certain minimum SNR associated with a BER and the number of bits chosen such that the overall SNR is above the minimum value [21]. Another one is the desired signal is narrowband compared to the bandwidth digitized and nearby there are powerful blocking interferers [21]. Although the blocker can be filtered out in the digital domain, there could be spurs that fall in the same band as the desired signal, generated by non-linearity of ADC conversion [21]. For reliable detection of the desired signal, the power of largest spur should be below the minimum of SNR [21]. Therefore, it requires the ADC to have a certain minimum value. The high SNR needed for reliable detection implies a high A/D resolution. Hence, the modeling of AWGN, interference and quantization noise is done differently. The large bandwidth is utilized at low

power levels and low received SNR's. The ADC has a variable range of maximum and minimum values due to the different amplitude which is the square root of the power and thus the quantized values are obtained from the quantization process. The power control is varied by varying the transmitted power such that at the receiver the sufficient SIR is maintained for each transmission. The interference signal for 3,6,10, -10 dB observed for two users with respect to the desired signal for 2 and 8 bits. Also, the diminishing return value is measured for the 3 dB and 6 dB for different number of bits to evaluate their performance.

4.4.2 Simulation Method and Results

In the first case, consider two users in the Asynchronous CDMA system. Here the amplitude of desired user signal is held constant, and the amplitude of the other user is varied, and the power domain is 2,4 times more powerful than the desired signal. So, the amplitude of the desired signal and the interfering signal i.e., user 2 is $\sqrt{2}$ then the ratio of power for user 1 and user 2 is 3dB. Then when the amplitude of user 2 is changed to $\sqrt{4}$ then the ratio of the power for 2 users is 6 dB which is evident as there is the difference in signal power. Then the transmitted signal is added with the noise and interference signal and despread and used for quantization process where the maximum value is added to 1 and rounded up so that the ADC resolution fits within the range and can get the quantized values. The range will differ for different power for the received signal and the quantized values are compared with the transmitted bits to get the BER. The simulation is done 100000 times for two users of processing gain 30 in AWGN channel and the power factor and the amplitude are calculated for

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3 and 6 dB for 2 and 8 bits quantizer. The simulation results are shown below.

System Parameters	Value
Number of message bits	100000
Number of quantization bits	2,8
Processing gain	30
Power factor	3,6,10, -10
Number of users	1,2

Table 4.3: Parameter of the System Model



FIGURE 4.5a: BER versus SNR (dB) as parameterized by the number of users (N=1,2) for bits (b=2,8) for power (3,6 dB) of Asynchronous CDMA systems of Near Far Effect

It is observed that in asynchronous CDMA the curves will go upward for a smaller number of bits for the different amplitude and different power for two users. We see that when the amplitude increases then the power also increases for the interference signal comparatively to the desired signal. For 2 users and for 8-bit quantizer the BER is less comparatively to the 2-bit quantizer for example for interference signal of 3 dB at SNR 6 dB for 8-bit quantizer the BER is 0.0115 and for 2-bit quantizer the BER is 0.036 which is high whereas for interference signal of 6 dB at SNR 6 dB for 8-bit quantizer the BER is 0.02519 and for 2-bit quantizer the BER is 0.068 which is more. Therefore, for the 2 users the low power 3 dB has a better performance than the 6 dB which acts as a strong interference signal and gives worst performance at low quantizer bits.

In the second case, consider two users in the Asynchronous CDMA system. Here the amplitude of desired user signal is held constant, and the amplitude of the other user is varied, and the power domain is 2,4,10,1/10 times more powerful than the desired signal. So, the amplitude of the desired signal and the interfering signal i.e., user 2 is $\sqrt{2}$ then the ratio of power for user 1 and user 2 is 3dB. Then when the amplitude of user 2 is changed to $\sqrt{4}$ and $\sqrt{10}$ then the ratio of the power for 2 users is 6 dB and 10dB which is evident as there is the difference in signal powers. The last case is when the power of user 2 is 10 times less to user 1 i.e., 1/10 and the amplitude is $\sqrt{1/10}$ then the power of the second user is -10dB. This simulated the detecting of the wanted signal when it is both far (-10dB) and near (+10dB). Then the transmitted signal is added with the noise and interference signal and despread and used for quantization process where the maximum value is added to 1 and rounded up so that the ADC resolution fits within the range and can get the quantized values. The range will differ for different power levels for the received signal and the quantized values are compared with the transmitted bits to get the BER. The simulation is done 100000 times for two users of processing gain 30 in AWGN channel and the power factor and the amplitude are calculated for 3, 6, 10, -10 dB for 2 and 8 bits quantizer. The simulation results are shown below.

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FIGURE 4.5b: BER versus SNR (dB) as parameterized by the number of users (N=1,2) for bits (b=2,8) for power (3,6,10, -10 dB) of Asynchronous CDMA systems of Near Far Effect

It is observed that in asynchronous CDMA the curves will go upward for a smaller number of bits for the high power for two users. It is seen that when the amplitude increases then the power also increases for the interference signal comparatively to the desired signal. And when the power of the interfering signal is -10dB it represents a weaker signal which is evident from the figure that this interfering signal almost matches with the desired signal for 2-bit and 8-bit quantizer which shows very low power interference. On the contrary when the power is more for the second user then the interference is stronger and BER is rising. For 2 users 8-bit quantizer the BER is less comparatively to the 2-bit quantizer for example at SNR 6 dB for 8-bit quantizer for interference signal of 3,6,10 dB the BER is 0.01105, 0.02508, 0.06981 and for 2-bit quantizer for interference signal of 3,6,10 dB the BER is 0.03939, 0.07662, 0.21501 which showcase that the higher bit quantizer for low power level gives a better performance rather than the low bit quantizer values with high power level which in this case is 10 dB acts as a strong interference signal.

The last case, consider two users in the Asynchronous CDMA system for 3dB and 6 dB separately getting the BER for 2,3,4,6,8,10 and 12 bits to find out the diminishing return which will show that at a certain bit the results for other bit values will be statistically similar and they will not provide any better results. Here the amplitude of desired user signal is held constant, and the amplitude of the other user is varied, and the power domain is 2,4 times more powerful than the desired signal. So, the amplitude of the desired signal and the interfering signal is $\sqrt{2}$ and the power ratio for user 1 and user 2 is 3dB whereas it is 6 dB when the amplitude of user 2 is changed to $\sqrt{4}$ and the cases are measured separately. Then the transmitted signal is added with the noise and interference signal and despread and used for quantization process where the maximum value rounds up so that the ADC resolution fits within the range and can get the quantized values. The range will vary for different power for the received signal and the quantized values are compared with the transmitted bits to get the

BER. The simulation is done for 100000 times for two users of processing gain 30 in AWGN channel. In one case the power factor is taken 3 dB for 2,3,4,6,8,10,12-bit values and in another case for 6 dB for 2,3,4,6,8,10,12 bits quantizer the BER values are computed. The simulation results are shown below.

Table 4.4: Parameter of the System Model

System Parameters	Value
Number of message bits	100000
Number of quantization bits	2,3,4,6,8,10,12
Processing gain	30
Power factor	3,6
Number of users	1,2



FIGURE 4.5c: BER versus SNR (dB) as parameterized by the number of users (N=1,2) for bits (b=2,3,4,6,8,10,12) for power 3dB of Asynchronous CDMA systems of Near Far Effect





From the figure it is seen when the signal is large comparatively to the interferer in amplitude terms a low bit resolution suppresses the effect of the latter [21]. For 2 bits during the portion of the window where there is signal the ADC output saturates and for other bits there is only interference and no signal [21]. The ADC output has less variations for higher bit resolutions. When the bits are higher for large interfering signals it gives a more appropriate design [21]. Due to the diminishing returns it goes for higher resolution. It is observed that for 3dB the curve goes more downward with the increasing number of bits compared to the 6 dB signal. The diminishing return for 3 and 6 dB is 4 bits after that the other bit results synchronize with each other and its indistinguishable from the resolution curve. For power 3 dB at SNR 6 dB for 3,4,6,8 bit the BER values are 0.017, 0.01306, 0.01104, 0.01117. Besides, for power 6 dB at SNR 6 dB for 3,4,6,8 bit the BER values are 0.03232, 0.02629, 0.02508, 0.02491. It clearly depicts that 6 dB interferer is stronger than the 3 dB interference signal for which the 6 dB gives a little worst performance compared to 3 dB.

Chapter 5

Simulation for the Comparison of MIMO Systems

5.1 MIMO System Model

5.1.1 Classification of Antenna Configuration

There are different ways to classify the antenna configuration. The performance of wireless communication systems is enhanced by these techniques. Single input single output (SISO) is the basic communication system, which uses one transmitted antenna and one received antenna and the model for the communication channel has only one input and one output. The reliability of data transfer over SISO is little bit low so to improve the performance of the communication system, multiple antennas are used at the receiver or at the transmitter to enhance the reliability or the capacity of channel [5].

The communication channel models in a single input multiple output communication system (SIMO), has a single input and multiple output. The signal which is transmitted from a single transmitter arrives at each receive antenna through different paths due to the multipath propagation [5]. This is called receive diversity. The probability of errors can be reduced by using this technique, that is by increasing the number of received antennas and reducing the fading of the transmitted signal, which means increasing the reliability of the wireless communication channel [5]. Also, when the signal to noise ratio is large, the capacity of the communication

channel logarithmically increases with the number of the receive antennas.

In multiple input single output (MISO) technique, the communication channel models as a multiple input and single output which is called transmit diversity. The receiver only receives one signal that was transmitted over transmitted antenna if the channel has the knowledge of the channel state information at receiver (CSIR) only. The reliability and the channel capacity in this case are the same for both MISO-CSIR only and SISO [5]. On the other hand, if the channel information is available at both the transmitter and receiver which are the CSIR and channel state information at transmitter (CSIT), the transmitter can decide which one of the transmit antennas will be used to transmit data to the single receiver antenna and it will be able to divide its power such that more of its power is allocated to that particular channel which has the least amount of fading thus increasing the capacity to be more than that of a SISO channel for the same transmitted power. As the channel capacity will logarithmically increase with the increased number of transmit antennas hence the reliability of the MISO system will increase [5].



(a) Single Input Single Output (SISO)



(d) Multiple Input Multiple Output (MIMO)

FIGURE 5.1: Classification of multiple antenna configurations

As figure 5.1, shows the compared SISO, SIMO and MISO system, MIMO system has more transmission antennas and receiving antennas. The performance of the system will be better as

the multiple antennas can help suppress the channel fading and increase the throughput of the system. A multiple input multiple output (MIMO) system can be formed in the most promising way by achieving high data rate in wireless communications and using multiple antennas at both the transmitter and the receiver.

Multiple Input Multiple Output (MIMO) is a collection of signal processing techniques that have been developed to enhance the performance of wireless communication systems and this technique refers to using multiple antennas at the transmitter, receiver, or both [5]. Channel Capacity (maximum transmission data rate, Bits/s) and Performance (minimizing the probability of transmission error) are the two prime factors of any wireless system [22]. To achieve this, either the channel bandwidth or the transmit signal power must be increased. A well-designed MIMO system can achieve these two features without altering either bandwidth or signal power. The performance and channel capacity can be improved by either combating or exploiting multipath communication channels by featuring transmitter and receiver diversity (referred to as Spatial Diversity) and transmitting information in the form of streams (referred to as Spatial Multiplexing). It creates spatial diversity if the MIMO technique is used to combat multipath channels or creates spatial multiplexing if the MIMO technique is used to exploit multipath channels. The characteristic of the communication system depends on whether the focus of the MIMO technique is on creating spatial diversity, which improves reliability of communication channels, or it is the focus on increasing the data rate by performing spatial multiplexing (SM) [5]. Figure 5.2 shows the block diagram of MIMO system where the transmitted data signals pass through multiple paths to get to the receiving antennas and there

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is also noise that interferes with the data signals along the paths.



FIGURE 5.2: A detailed structure of a MIMO system

The MIMO systems can be represented as,

r=H.s+n

where r represents received vector, s represents transmitted vector, H represents the channel

vector matrix and n represents noise vector.

For a 2x2 MIMO system, the expression reduces to:

$$\begin{bmatrix} r1\\ r2 \end{bmatrix} = \begin{bmatrix} h11 & h12\\ h21 & h22 \end{bmatrix} \cdot \begin{bmatrix} s1\\ s2 \end{bmatrix} + \begin{bmatrix} n1\\ n2 \end{bmatrix}$$

Table 5.1: Relationship of the MIMO concepts

MIMO Technique	Purpose	Method	
Spatial Diversity	Reliability is improved	Space time coding	
Spatial Multiplexing	Capacity is increased	Spatial demultiplexing	

5.2 Multiplexing Trade off

MIMO technique is used to enhance performance of communication system. The technique that is used to get spatial diversity and spatial multiplexing there is always a tradeoff between them. For example, if space time coding is used, the maximum diversity is achieved, but also get minimum capacity, spatial rate represents the capacity of the MIMO system. On the contrary, if spatial multiplexing technique is used, such as VBLAST, maximum capacity is achieved, but also there is minimum spatial diversity.

5.3 Space Time Block Coding

In wireless communications, transmitting multiple copies of a data stream across several antennas and exploiting the various received versions of the data to improve the reliability of data transfer space time block coding technique is used. It is also defined as diversity is achieved if compared with SISO then it has got more than one channel between transmitters and receivers.

Some well-known STBC's are Alamouti and orthogonal space time block coding (OSTBC) which deals with multiple transmit and receive antennas. STBC is designed to allow for increased

wireless transmissions knowing that the signal might encounter delay or different SNR ratios.

Through spatial channels additional noise and other losses are compensated by STBC which can

help reduce bit error rates. STBC codes can be classified into two types:

Orthogonal Space-Time Block Codes and Quasi-Orthogonal Space-Time Block Codes.



FIGURE 5.3: Classification of space time block coding

5.4 Orthogonal Space Time Block Coding

Orthogonal STBC (OSTBC) are full diversity coding techniques that are predominantly used in MIMO communications and the code rate of OSTBC codes is less than or equal to one. Alamouti coding has both full code rate and full diversity which is the only OSTBC code [22].

5.5 Alamouti Space Time Block Coding

The Alamouti STBC is a complex space-time diversity technique that can be used in 2x1 MISO case or in a 2x2 MIMO mode. It is the only STBC that without sacrificing its data rate it can achieve its full diversity gain. Even though higher-order Space-Time Block Codes (STBCs) offer superior error-rate performance, Alamouti's code usually has a significant advantage due to this characteristic [7]. It consists of four basic functions: Space time coding, diversity combining, channel state information and maximum likelihood decoding. The schematic diagram shows the basic function operate in a 2×2 Alamouti STBC.



FIGURE 5.4: 2×2 Alamouti Schematic diagram [22]

In the 2x2 Alamouti STBC, from the two transmit antennas, information is sent at two-time slots. Let x1 and x2 be the symbols for the information. In the first time slot, symbols x1 and x2 will get transmitted from each transmit antenna. Then in the second time slot, symbols $-x2^*$ and x1* will be transmitted again. In this way, the spatial and time dimensions are involved in Alamouti Coding.

Time	Transmitter 1	Transmitter 2
Time t	X ₁	X ₂
Time t+T	$-X_{2}^{*}$	X ₁ *

Table 5.2: Space time representation for Alamouti two transmit antennas.

Table 5.2 shows that two symbols and their complex conjugate are sent in two time slots, which brings a diversity gain without having to compromise on the data rate [7]. At the receiver the transmitted symbols will suffer from channel fading and noise over the air and their sum will be received. The following expressions show the received signals at the transmitters.

In time slot 1 received data Rx1: y₁₁=x₁h₁₁+ x₂h₁₂+n₁₁

In time slot 2 received data Rx1: y_{12} =- x_2 * h_{11} + x_1 * h_{12} + n_{12}

In time slot 1 received data $Rx2: y_{21}=x_1h_{21}+x_2h_{22}+n_{21}$

In time slot 2 received data Rx2: $y_{22}=-x_2*h_{21}+x_1*h_{22}+n_{22}$

Where x_1 and x_2 are transmitted data, x_1^* and x_2^* are complex conjugate of x_1 and x_2 , y_{11} and y_{21} received data for first time slot, y_{12} and y_{22} received data for second time slot, h_{11} , h_{12} , h_{21} and h_{22} are multiplicative fading coefficients for Rayleigh channel (such as h_{11} are Rayleigh coefficient from transmit antenna 1 to receive antenna 1, h_{12} are Rayleigh coefficient from transmit antenna 2), n_{11} , n_{22} and n_{22} are AWGN noise.

After taking conjugates of y_{11} and y_{22} to get rid of conjugates of transmitted data at the receiver,

 $y_{12}^*=-x_2 h_{11}^*+x_1 h_{12}^*+n_{12}^*$

 $y_{22}^* = -x_2 h_{21}^* + x_1 h_{22}^* + n_{22}^*$

Therefore, the equations are-

 $y_{11}=x_1h_{11}+x_2h_{12}+n_{11}$

 $y_{12}^*=-x_2 h_{11}^*+x_1 h_{12}^*+n_{12}^*$

 $y_{21}=x_1h_{21}+x_2h_{22}+n_{21}$

 $y_{22}^* = -x_2 h_{21}^* + x_1 h_{22}^* + n_{22}^*$

We get, Y=HX+N

As the columns are orthogonal in Alamouti case,

$$H^{H} = \begin{bmatrix} h_{11}^{*} & h_{12} & h_{21}^{*} & h_{22} \\ h_{12}^{*} & -h_{11} & h_{22}^{*} & -h_{21} \end{bmatrix}$$
$$H^{H} H = \begin{bmatrix} |h_{11}|^{2} + |h_{12}|^{2} + |h_{21}|^{2} + |h_{22}|^{2} & 0 \\ 0 & |h_{11}|^{2} + |h_{12}|^{2} + |h_{21}|^{2} + |h_{22}|^{2} \end{bmatrix}$$

d= H^HY

5.6 Simulation Method and Results



FIGURE 5.5: Simulation Flow chart [22]

Step 1: Define initial setup parameters such as the number of transmitters, receivers, transmitted bits, modulation type, fading channel, and SNR.

Step 2: Generate input bits using the MATLAB command for random generation.

Step 3: Modulate the generated bits with the specified modulation type.

Step 4: Transform the modulated bits into the Alamouti codeword form using matrix transformations.

Step 5: Model the fading channel using i.i.d Gaussian random variables with zero mean and unit variance to generate a channel matrix for each transmitting antenna.

Step 6: Generate the received signal by adding random noise to the Alamouti codeword and channel matrix.

Step 7: Calculate the estimated transmitted bits using the decoding process.

Step 8: Demodulate the calculated estimates.

Step 9: Compare the demodulated bits with the input bits to determine the number of error

bits. Calculate the Bit Error Rate of the system by dividing the error bits by the total transmitted bits.

Step 10: Repeat all the steps for different SNR values.



FIGURE 5.6: Comparison of BER Performance for BPSK modulation with transmit verses receive diversity in Rayleigh fading (Results verified through comparison with [23])

Types of	No. of Tx	No. of Rx	BER	SNR (dB)
Schemes	antenna	antenna		
SISO	1	1	0.053	6
1×1				
SIMO	1	2	0.0081	6
1×2				
MISO	2	1	0.024	6
2×1				
MIMO	2	2	0.0004	6
2×2				
Theoretical	2	2	0.023	6
2 nd order				
diversity				

Table 5.3: BER values for some of SNR values of different schemes by using BPSK modulation.

From figure 5.6 it is observed that for the 2×1 Alamouti case at the BER 0.008 the SNR is 9dB and the 1×2 Maximal Ratio Combining case the SNR is 6dB which shows there is a 3dB loss due to the power splitting across the two transmit antennas. The table shows the difference of different schemes at constant SNR of 6 dB. SISO with 1×1 antenna gives the BER of 0.053, MRC with 1×2 antenna gives BER of 0.0081, MISO with 2×1 antenna gives BER of 0.024 and Alamouti 2×2 antenna gives BER value 0.0004 which shows the performance of MRC is better than MISO and MISO and theoretical 2nd order diversity is almost similar. It can be deduced from the figure that the Alamouti 2×2 case performance is better as the BER value is less here also it has got a greater number of antennas in both the transmission and receiving sides and four possible channel matrix comparatively to others.



FIGURE 5.7: BER Performance of STBC coded systems and other comparison (Results verified through comparison with [24])

From figure 5.7 it is seen that as the modulation order increases in QPSK compared to BPSK more energy is required to achieve the same BER as there is an increment in the number of bits per symbol to be processed. 2×2 Alamouti MIMO system at 8dB the BER is 0.00051, for OSTBC using QPSK modulation the BER is 0.00322, the MRC the value is 5.86×10⁻⁵, theoretical 4th order diversity using QPSK modulation the value is 0.0037 and the no diversity case the BER is

0.0357.Therefore the Alamouti using BPSK modulation shows better performance than OSTBC using QPSK modulation and the OSTBC results overlap with the theoretical 4th order diversity case using QPSK modulation. And in the SISO case i.e., no diversity result is weaker and MRC using BPSK is better among all of them as it has got a greater number of received antennas.

5.6 Proposed Work

Spatial Multiplexing (SM) which employs multiple antennas at transmitter as well as at receiving side is mainly responsible for high data rate transmission hence spectral efficiency enhancement in MIMO (Multiple Input and Multiple Output) systems without additional bandwidth and power requirement is achieved. Several research have been developed for demultiplexing and decoding as spatial demultiplexing at receiver end is a difficult task [25]. There are three signal detection methods namely Zero-Forcing (ZF), Minimum Mean Squared Error (MMSE) and Maximum Likelihood (ML). In ZF method noise enhancement is the problem and in ML method the complexity for the implementation is higher whereas the complexity of implementing MMSE is much lower, and the performance is much better in comparison to ZF [25]. So, the MIMO Spatial Multiplexing technique is analyzed for different antenna configurations (1×1, 2×2, 4×4,8×8) in independent Rayleigh faded AWGN channel for different modulation schemes such as BPSK, QPSK, 16 QAM and 64 QAM. The MMSE detector is employed at the receiving end to eliminate the inter symbol interference and to improve the performance of the system hence the performances are compared for different antenna configurations.

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5.7 Spatial Multiplexing

Spatial Multiplexing is a technique which is responsible for increment in spectral efficiency of MIMO systems by transmitting independent streams from independent antennas. SM involves the splitting up a long data stream into smaller chunks of data, modulating each data stream separately and transmitting all the data chunks simultaneously from different transmit antennas [6]. This implies that the data stream can be split into as many smaller chunks as the number of transmitting antennas available. The channel information is known to the receiver and is used to demodulate each signal then combine all the chunks to get back the original full length data stream. SM has the benefit of increasing the data rate without increasing the available bandwidth or the transmitter power. As the number of transmitting and/or receiving antennas increases so spatial multiplexing essentially increases the capacity of a MIMO channel, and this is referred to as the multiplexing gain [6]. When the transmitting or the receiving antennas are not equal in number then multiplexing gain depends on the minimum of their TX/Rx antennas.

The data streams corrupted by noise interfere with each other at the receiving antenna side, so equalizer is needed to mitigate inter symbol interference. For this purpose, two types of equalizers can be employed at the receiving side, one is linear, and another is non-linear. Zero Forcing (ZF) and Minimum Mean Square Error (MMSE) equalizers are kind of linear equalizers as linear receivers are used in majority of cases due to their low computational complexity and implementation is also easy [8]. Maximum likelihood (ML) comes in the category of nonlinear equalizers which is optimal but offers high computational complexity. Spatial Multiplexing requires that the number of receiving antennas is either greater than or equal to the number of transmitting antennas. The different data streams are sent in the same frequency domain and with the same transmission power from different transmitting antenna as all the data streams follow different paths to reach the receiver [8]. The maximum spatial streams are limited to minimum number of transmit and receive antennas. Spatial Multiplexing can be implemented with or without channel knowledge.

5.8 Equalizers

ZF Method:

When inter symbol interference dominates noise, then zero forcing equalizer can be used to recover the transmitted streams in case of MIMO Spatial Multiplexing. This equalizer uses the inverse frequency response of channel to perform equalization operation. By applying the inverse function, the overall response of desired symbol equal to one and zero for all other symbol hence removing the inter symbol interference but on the contrary, the noise is enhanced [26]. The algorithm for ZF equalizer is given by:

 $W_{ZF} = (H^{H}H)^{-1}H^{H}$

$$\widetilde{x}_{\mathsf{ZF}} = \mathsf{W}_{\mathsf{ZF}} \mathsf{y}$$

where \widetilde{x}_{zF} is the estimated ZF symbol.

MMSE Method:

The MMSE detector is used for the computing of the noise variance for reducing noise amplification. MMSE detector is a linear detector which minimizes the average mean square error between the transmit vector and the estimated received vector. This is a very standard and optimized scheme because interference and noise both are reduced [26]. In this case, the detector coefficient W_{MMSE} as-

 $W_{MMSE} = [H^{H}H + N_{o}I]^{-1}H^{H}$

 $\widetilde{x}_{\text{MMSE}} = \mathbf{W}_{\text{MMSE}}^{\text{H}} \mathbf{y}$

where \widetilde{x}_{MMSE} is the estimated MMSE symbol.

ML Method:

ML detection is based on calculating the Euclidean distance between the received signal vector and the product of all possible transmitted signal vectors and the given channel H and the one with minimum distance is found out [25]. The ML method determines the estimated symbol vector as-

\widetilde{x}_{ML} = arg min _{xec} ||Y-HX||²

where \tilde{x}_{ML} is the estimated ML symbol. The ML decoder has higher hardware complexity as the order of modulation increases with received symbols. Due to increasing modulation order the number of all possible combinations of the transmitted symbol also increases.

5.9 Signal detection method and Results



FIGURE 5.8: MIMO Spatial Multiplexing System

The modulation schemes considered are BPSK, QPSK, 16-QAM and 64 QAM. Initially generating random binary sequence of length 1000. Multiplying the transmitted symbols with the channel matrix and then adding white Gaussian noise to it. The received symbols are then equalized and demodulated by performing hard decision decoding. Repeat the above steps for the whole length of data bits to be transmitted. Then it is compared with the original data to calculate the BER. The above steps are repeated for different values for Signal to Noise Ratio (SNR). Repeat the above steps for multiple values of iterations and average values of BER are considered.



FIGURE 5.8: BER Performance of MIMO using BPSK modulation



FIGURE 5.9: BER Performance of MIMO using QPSK modulation



FIGURE 5.10: BER Performance of MIMO using 16 QAM modulation



FIGURE 5.11: BER Performance of MIMO using 64 QAM modulation

Modulation	SNR (dB)	1×1	2×2	4×4	8×8
BPSK	4	0.080	0.048	0.027	0.016
	10	0.022	0.011	0.008	0.003
	18	0.0031	0.0026	0.0012	0.0005
QPSK	4	0.127	0.097	0.071	0.054
	10	0.044	0.034	0.022	0.016
	18	0.006	0.007	0.004	0.003
16 QAM	4	0.291	0.292	0.287	0.286
	10	0.154	0.156	0.159	0.163
	18	0.037	0.035	0.042	0.050
64 QAM	4	0.366	0.365	0.368	0.369
	10	0.261	0.276	0.284	0.291
	18	0.108	0.115	0.129	0.158

Table 5.4: Comparison for different antenna configurations for MIMO system employingMMSE equalizer using different modulation schemes.

From the figure and the table values it shows the relationship between BER and SNR using BPSK, QPSK, 16-QAM and 64-QAM modulation scheme. In figures 5.8 and 5.9, when SNR increases the value of BER becomes smaller. When the number of antennas increases the BER becomes smaller. For 1×1 system, which is also called SISO system, it has the biggest BER value than other three cases. From figure 5.10 and 5.11, when SNR increases the value of BER becomes smaller. The three lines don't have much difference between each other as the three lines in the former cases. At the initial position they are almost overlapping together and as the value of SNR becomes bigger, they gradually separate from each other. Hence, the table values deduced the same results as explained here.

Therefore, the value of BER gradually decreases when the value of SNR increases and when the number of antennas increases in both transmission end and receiving end, the BER value becomes smaller. Both in theory and practical scenarios, at low SNR, the MMSE is giving a better

performance than ZF and ML. At high SNR values the MMSE will start to resemble the ZF equalizer. Furthermore, the performance of MIMO system is generally better than the performance of SISO system.



FIGURE 5.12: Comparison of BER Performance of MIMO using BPSK and QPSK modulation

The figure shows the performance of MIMO SM technique employing MMSE equalizer in independent Rayleigh faded AWGN channel presented for antenna configurations 4×4 for BPSK and QPSK modulation schemes. It is observed that with the increasing SNR value the BER value decreases and for higher modulation order i.e., for QPSK modulation the BER value is higher comparatively to BPSK modulation.

Chapter 6

Simulation of LDPC codes with quantization

6.1 Linear Block Codes

Linear block codes concatenate the redundant bits which are used for error correction to the transmitted data. The parity bits are the additional bits that are added to the transmitted data and error occurs due to these bits' corruption or number of 1's in the information bit sequence different from the number that is used to compute the parity bits [9]. A binary block code generates a block of n coded bits which are called codeword symbols from k message bits. For error detection and correction, redundancy is being provided by n-k when n>k. 2^k different inputs are available for k input messages and code rate, R=k/n. In linear block codes, each bit is the linear combination of other bits. The encoding of linear block code is achieved from the generator matrix, G at the transmitter whereas at the receiver the parity check matrix, H is performed at the decoding. The received codeword C_i is valid if C_iH^T=0 means the product of valid codeword and H results in all zero vectors [9]. Standard array and syndrome are two methods to perform the decoding of linear block codes [9]. Classical block codes and LDPC codes differs in their decoding algorithms like classical block codes use Maximum Likelihood (ML) algorithm, but LDPC codes uses iteratively message passing algorithm based on graphical representation of their parity check matrix [9].

6.2 LDPC Codes

In wireless communication LDPC codes received remarkable attention for the best performance of its error correction near Shannon limit for large code lengths [27]. LDPC codes are the linear block codes that have the feature of sparseness of their parity check matrix H of size n×m. Due to its sparsity, H contains more zeros than non-zero entries which ensures the efficiency for low complexity at the decoding side [27].

In LDPC codes for 5G two base parity check matrices 46×68 and 42×52 used called Base Graphs. They employ the base graph which is a structured parity check matrix corresponding to the input length and code rate. This code is flexible for all block sizes and has better spectral efficiency and supports high throughput for 5G New Radio (NR).

The parity check matrix can also be represented by a graphical form known as Tanner graph which plays an important role in the decoding algorithm of LDPC codes where iterative probabilistic decoding algorithms are used [27]. The Tanner graph is composed of two nodes: check node and variable node. In matrix H each row corresponds to check node i.e., message bits and the column represented by variable node which is code bits [27]. The 1's in the matrix H shows the H between check nodes and variable nodes. The illustration of the Tanner graph is shown below.



FIGURE 6.1: Tanner Graph

6.3 Base Graphs and Parity Check Matrix

6.3.1 Base graphs analysis

There are two kinds of base graphs, base graph 1 with 46 rows and 68 columns and base graph 2 with 42 rows and 52 columns for 5G NR. Code rate and size of information bits are the determining factor of their usage [10].

For base graph 1,

K=22Z_c

Where K is the maximum number of information bits and Z_c is the lifting size which are 51 in numbers in total, and it varies between 2 to 384 for each base graph [10]. In base graph 1, Z_c is 16.

Both base graphs have the same block structure, and the columns include information column, core parity column and extension parity columns [10]. The rows are divided into core check rows and extension check rows [10]. It has sub matrix that is double diagonal matrix which is benefit for encoding [10].



FIGURE 6.2: Base graphs block structure [10]

6.3.2 Parity check matrix calculation

By replacing each element of base graph H_{BG} with a $Z_c \times Z_c$ matrix the parity check matrix H is

obtained based on the following rules.

- The size will be Z_c× Z_c and each element containing value -1 in H_{BG} will be replaced by an all zero matrix.
- The size will be Z_c× Z_c and each element containing value 0 in H_{BG} will be replaced by an identity matrix.

3. If circular permutation matrices $I(P_{i,j})$ are substituted for each element of value 1 to Z_{c} -1 in H_{BG} , denoted by $P_{i,j}$, then the matrix size will be $Z_{c} \times Z_{c}$, where i and j are the row and column indices of the element. The circular permutation matrix $I(P_{i,j})$ is created by shifting the $Z_{c} \times Z_{c}$ identity matrix I to the right $V_{i,j}$ times [10].

A simple example is shown assuming B is a base graph with lifting size 4 to explain the principle of getting the parity check matrix.

$$B = \begin{bmatrix} 2 & -1 & 1 & 3 & 0 & -1 \\ 1 & 0 & -1 & 0 & 0 & 0 \\ -1 & 3 & 2 & 1 & -1 & 0 \end{bmatrix}$$





FIGURE 6.4: Parity check matrix H

6.4 LDPC Encoding

Double diagonal structure in base graphs of the parity check matrix is used in LDPC encoding for efficient computation and low complexity [11]. LDPC encoding adds redundant bits to the message bits to get codeword which will be transmitted to the receiver. The message bits to be

encoded has k number of message bits and the redundant bits which is the parity bits has n-k=l number of parity bits and the encoded message which is called the codeword has n number of encoded message bits. Therefore, the codeword bits vector can be derived from the message bits vector and parity check bits vector equation of, c= [m p].

6.5 LDPC Decoding

The decoding of LDPC code is performed to satisfy the parity check conditions, CH^T=0 by the process of iterative processing based on the tanner graph [9]. The received codeword is valid if the condition is being fulfilled. There are two types of decoding one is hard decision and the other is soft decision decoding algorithm. The hard decision decoder is when the message passed contains the actual value of bits that can either be 0 or 1 like the Bit Flipping Algorithm [10]. Soft decision decoding occurs when the message passed is the probability value that can distinguish between the set of quantized values between 0 and 1 and these values associated with the occurrence of a particular bit and the sum product algorithm is based on the idea of a belief propagation which is the soft decision message passing algorithm [10]. In the message passing algorithm during each phase the messages passed from message nodes to check nodes and from check nodes back to message nodes in the tanner graph. Depending on the operations and type of message, the message passing algorithm may differ such as in bit flipping algorithm the message would be binary in comparison to belief propagation algorithm where the probabilities of incidence of codeword bits constitute the message and are represented with log likelihood ratios (LLR) [9].

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6.6 Hard Decision Decoding Algorithm

Bit flipping algorithm is a method used by hard decision decoding for LDPC. In bit flipping algorithm (BF) the input data are the binary bits and if error is being detected in the binary sequence, then the bits are flipped to 0 or 1 accordingly [28]. The process is done by computing the syndrome vector and updating the received vector for each iteration based on the parity check equations [28].

6.7 Soft Decision Decoding

6.7.1 Soft Decision Decoding Algorithm

Soft decision decoding is based on the belief propagation algorithm which is called sum product algorithm that relies on the message passing algorithm. The probabilities in the case of sum product algorithm (SPA) are expressed in log likelihood ratios which represent the matrix for a binary variable by a single value [9]. The main difference between SPA and BF is each decision is represented with probabilities of information bits. SPA provides lower complexity in log domain than in probability domain that makes the algorithm much simpler [9]. Soft decision iterative decoding algorithm process soft information (real numbers) through the tanner graph and offer better error performance than hard decision decoding. Two features sum product and min sum algorithm of soft decision decoding is described in detail.

6.7.2 Sum Product Algorithm

Sum Product algorithm known as Belief Propagation algorithm based on logarithmic domain. The input to the LDPC decoder depends on the following decoding algorithm:

$$L(c_i) = \log \frac{P_r(c_i = 0|y_i)}{P_r(c_i = 1|y_i)} = \log \frac{P_r(x_i = +1|y_i)}{P_r(x_i = -1|y_i)}$$

Where **L(c**_i) is the input LLR to the decoder.

The SPA consists of 4 steps. The initial step is to initialize information and variable nodes [29]. Next is to check node update [29]. Then update the variable node. The final step is the decision and decoding.

6.7.3 Min Sum Algorithm

Min Sum algorithm (MSA) relies on the iterative process of information transmission between check node and variable node. The MSA for LDPC decoding is a reduced complexity as it can efficiently compare the lowest reliable on the check node to detect each variable node output [29]. The operation on check nodes is same for both MSA and SPA except the variable node's conditions are different. The implementation of MSA is shown below:

Steps	Operations
1	Initial the channel messages for each variable node. L=r Bowel
	Where r is the input channel message to decoder.
2	Update messages passing matrix via
	min2= min (abs (Rcv _{ii}))
	\widetilde{x} =sign (Rcv _{ij})
	parity= $\prod \tilde{x}$
	Rcv _{ij} = parity×ĩ× Rcv _{ij}
3	Lindate the output LLR via
	L=L+∑ Rcv _{ij}
4	Update messages passing matrix via
	Rcvij=L- Rcvij
5	Make decisions.
	Ĝ = 1. if L<0
	0, else
6	if (H $\hat{c}^{T}=0$) or (iterations=max iterations)
-	Or (other stopping rule)
	Ston
	Stop
	cise go to step 2.

Table 6.1: Implementation of Min Sum Algorithm [10]

- 1) Set all non-zero receive values to their initial values.
- 2) Determine the minimum absolute value and update the message passing matrix. For each row in the matrix, identify the minimum absolute value (m₁) and its index position (pos), followed by the second minimum absolute value (m₂). Replace m₁ with m₂ and replace the other values with m₁. Assign a sign to each element.
- 3) Update the output Log-Likelihood Ratio (LLR).
- 4) Update the message passing matrix.
- 5) Make decisions based on the updated information. Repeat steps 2 to 5 until the maximum number of iterations is reached.

6.8 System Model

Figure 6.5 and table 6.2 show the block diagram and parameters of the system model for LDPC codes which uses BPSK modulation and AWGN channel. Initially the base graph 46×68 is used, and parity check matrix is created from it. The random generated message is encoded with LDPC code for transmission. The encoded message is produced from the message bits and the H matrix and then the transmitted signal added to the AWGN channel. The received codeword is decoded by soft decision iterative message passing layered decoding based on the layered min sum algorithm which is optimized implementation of MSA used for different iterations until **cH^T=0** and the estimated original message is recovered by means of BPSK demodulator. Then the errors are counted by comparing the message bits with the estimated message bit for each block hence the frame error rate calculated which is the number of block errors by number of

blocks. Thus, the Frame error rate (FER) performance of soft decision decoding algorithm is analyzed.



FIGURE 6.5: Block diagram of LDPC code

Table 6.2: Parameter of the System Model

System Parameters	Value
Base Matrix	46×68
Code Rate	0.3235
Number of message bits	352
Number of codeword bits	1088
Modulation	BPSK
Channel	AWGN
Decoded Methods of LDPC	Layered MSA
Number of Blocks	1000

6.9 Simulation Results



FIGURE 6.6: FER performance per SNR for Number of Blocks =1000 for LDPC code

SNR (dB)	FER	
0.5	1	
1	1	
1.5	0.967	
2	0.774	
2.5	0.354	
3	0.051	
3.5	0.002	

Table 6.3: FER verses SNR of block length=1000 with min sum decoding over AWGN channel

From the figure and table, it is observed that with high SNR and greater number of blocks the frame error rate performance is good using soft decision decoding algorithm. Here log likelihood ratios are considered which uses log domain and gives low complexity and layered message passing algorithms such as layered min sum algorithm which is optimized implementation of MSA have been used which is more efficient methods for decoding LDPC codes.

6.10 System Model of LDPC code with quantization effects

The FER performance of different quantization bits such as 1,2,4,6 bits are analyzed at rate 1/3, code length 1088 and offset 2 for BPSK modulation and AWGN channel with 0 and 1 mapped to -1 and +1 assumed and the soft decision decoding min sum algorithm under the LLR measure for soft quantized values simulated. Initially the base matrix 46×68 of the double diagonal structures to generate parity check matrix H used. The encoding is done systematically and at the output of the encoder a certain number of systematic bits are punctured which represents

an LLR zero that is fed into the decoder and these punctured bits never go into the circular buffer for efficient computation for which rate increases to 0.3333. Then the vector of the channel codeword is derived from the vector of the data bits and parity check matrix. Then, the iterative algorithms are implemented on the quantized fixed-point arithmetic. On the receiver side the analog to digital converter samples and digitizes the channel output and the resulting soft information represents each received bit with a real quantized number hence by using the layered MSA algorithm. For a q bit quantized iterative decoder, the received values are first clipped at a threshold C_{th} and then uniformly quantized into 2^q-1 quantization intervals within the range [-C_{th}, C_{th}] [12]. Each interval is represented by q quantization bits and the integer numbers { -(2^{q-1} -1), 2^{q-1} -1} are assigned to the intervals [12]. Thus, the received values under the LLR measure lies in this range and the operations in variable and check nodes are performed on integers [12]. The outgoing messages passed along each edge of the tanner graph are clipped to -(2^{q-1} -1) or 2^{q-1} -1 for negative and positive values [12]. Iterative decoding continues until it converges to a codeword, or the maximum number of iterations is reached [12]. Hence the Frame error rate (FER) performance of soft decision decoding algorithm for different quantization bits are analyzed.

Table 6.4: Parameter of the System Model

System Parameters	Value	
Base Matrix	46×68	
Code Rate	0.333 (due to punctured bits)	
Number of message bits	352	
Number of codeword bits	1088	
Number of quantizer bits	1,2,4,6	
Modulation	BPSK	
Channel	AWGN	
Decoded Methods of LDPC	Layered MSA	
Number of Blocks	1000	

6.11 Simulation Results



FIGURE 6.7: FER performance of quantization effects on LDPC code

	Quantization bits			
SNR (dB)	1	2	4	6
1	1	0.614	0.405	0.207
2	1	0.07	0.007	-

From the figure and the table, it is analyzed that with higher quantization bits such as for 6 bits that has got 64 levels the frame error performance is better than with low quantization bits like 1 bit which has 2 levels at high SNR where the performance degrades.

Chapter 7

Conclusion

This chapter will summarize the contents of the thesis and the possible extensions of research to expand upon the findings based on this thesis will also be discussed.

7.1 Summary

In chapter (2), we have discussed the evolution of wireless technologies, spread spectrum, the operation of DS-CDMA system, and the comparison between BPSK and QPSK modulation schemes. It also covers the simulation of synchronous and asynchronous CDMA systems and concludes that asynchronous CDMA systems experience more errors with increasing interference, while synchronous CDMA systems experience less interference and fewer errors with more users.

In chapter (3), we have discussed the simulation of Asynchronous CDMA systems for various parameters to observe the performance metrics, including the working principle and properties of multiple access detection. It also analyzes the performance of Bandpass signal in terms of magnitude and phase distortion of Asynchronous CDMA system. The chapter explores the impact of the number of users and different processing gains for the performance of BER and examines the near far effect. Simulations are conducted for different user cases to measure how amplitude and power increments affect the system performance.

In chapter (4), the effect of sampling and quantization on Asynchronous CDMA systems is investigated, and it is found that the quantization effect can cause significant performance degradation to the correlation receiver, especially when the MAI increases. The quantization effect on correlation receiver is analyzed for 2 and 4 user cases, and it is observed that performance degrades with more users and fewer bits. The near far effect of quantization is also evaluated, and it is found that higher bit quantizer for low power level gives better performance, and diminishing returns are measured for higher resolution.

In chapter (5), the focus was on the theoretical background and performance analysis of MIMO systems. The characteristics of different MIMO techniques, such as STBC, Spatial Multiplexing, and equalizers were described in detail. The simulation results showed that the performance of MIMO systems in terms of BER is better with increasing number of transmit and receive antennas. The Alamouti STBC technique was found to be better than the MRC technique, and the MMSE equalizer outperformed ZF and ML at low SNR values. Overall, the performance of MIMO systems was found to be better than the performance of MIMO systems was found to be better than the performance of MIMO systems was found to be better than the performance of MIMO systems was found to be better than the performance of MIMO systems was found to be better than the performance of MIMO systems was found to be better than the performance of SISO systems.

In chapter (6), the effectiveness of LDPC codes for error correction was explored, and it was shown that the performance of LDPC codes is dependent on their design and decoding algorithm. The FER performance of the soft decision iterative message passing layered decoding algorithm in the log domain of LDPC codes for AWGN channel using BPSK modulation was analyzed, and it was found that higher SNR and larger block sizes lead to better FER performance, and the use of log likelihood ratios reduces complexity. The use of a base graph

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for the base matrix 46x68 in encoding LDPC codes and the layered min sum algorithm in decoding was found to be efficient for the encoding and decoding of LDPC codes for 5G. Lastly, the FER performance of LDPC codes decoded by (quantized) soft decision decoding algorithms for different quantization bits was estimated, and it was observed that higher quantization bits lead to better FER performance.

7.2 Future Work

In this thesis, we have explored a number of important signaling techniques for 3rd,4th and 5th generation systems. In future work, it would be desired to explore additional signal methods, as well as combining multiple signaling methods.

- An interesting extension would be to simulate BER analysis of both Space time block code (STBC) and Spatial Multiplexing (SM) efficient multiple antenna transmission schemes with Orthogonal Frequency Division Multiplexing (OFDM) systems. By applying STBC MIMO-OFDM and SM MIMO-OFDM for Rayleigh fading channels for diversity techniques and different equalization techniques such as-ZF, MMSE and ML for multiple antenna arrangements to enhance the reliability, spectral efficiency and throughput can be proposed for future work.
- A good addition for future work would be to implement LDPC code for higher modulation scheme for different code rates for different block sizes.

- A brilliant addition to the future work would be the implementation of polar code and LDPC code and to compare and evaluate their performance between polar code and LDPC code for various code rates with different block lengths.
- Another great extension would be to explore the idea of analyzing the FER performance of MIMO system with LDPC code and for massive MIMO technology with LDPC code for uplink case.

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