Bit Error Rate Analysis of Channel Coding in Massive MIMO Systems

Kidist Yared Jillo

A Thesis Submitted to

The Department of Electronics and Communication Engineering

School of Electrical Engineering and Computing

Presented in Partial Fulfillment of the Requirement for the Master of Science Degree in Electronics and Communication Engineering

Office of Graduate Studies

Adama Science and Technology University

July, 2021

Adama, Ethiopia

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Co-Advisor: Dr. Rajaveerappa Devadas (Ph.D.)

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APPROVAL PAGE OF M.SC THESIS

I/we, the advisors of the thesis entitled "Bit Error Rate Analysis of Channel Coding in Massive MIMO Systems" and developed by Kidist Yared Jillo, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

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We, the undersigned, members of the Board of Examiners of the thesis by_Kidist Yared Jillo have read and evaluated the thesis entitled "Bit Error Rate Analysis of Channel Coding in Massive MIMO Systems " and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Electronics and Communication Engineering.

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DECLARATION

I hereby declare that this Master Thesis entitled "Bit Error Rate Analysis of Channel Coding in Massive MIMO Systems" is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Kidist Yared Jillo	________________________	________________
Name of the student	Signature	Date

RECOMMENDATION

I/we, the advisor(s) of this thesis, hereby certify that I/we have read the revised version of the thesis entitled "Bit Error Rate Analysis of Channel Coding in Massive MIMO Systems " prepared under my/our guidance by Kidist Yared Jillo submitted in partial fulfillment of the requirements for the degree of Master of Science in Electronics and Communication Engineering. Therefore, I/we recommend the submission of revised version of the thesis to the department following the applicable procedures.

Dr. Demissie Jobir (Ph.D.) ________________________ ________________

Major Advisor Signature Date

Dr. Rajaveerappa Devadas (Ph.D.) ________________________ ________________

Co-advisor Signature Date

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Page

LIST OF ABBREVIATIONS

4G	Fourth Generations
5G	Fifth Generations
BDMC	Binary input Discrete Memoryless Channel
BER	Bit Error Rate
BLER	Block Error Rate
BPSK	Binary Phase Shift Keying
BS	Base Station
CA-SCL	Check Aided Sequential Cancellation List
CN	Check Node
CRC	Cyclic Redundancy Check
CSI	Channel State Information
DL	Downlink
EE	Energy efficiency
I-CSI	Imperfect- Channel State Information
IEEE	Institute of Electrical and Electronic Engineering
ISI	Inter-Symbol Interference
LAN	Local Area Network
LDPC	Low-Density Parity-Check
LTE	Long Term Evolution
MIMO	Multiple-Input Multiple-Output
MISO	Multi-Input Single-Output
MMSE	Minimal Mean Square Error
OFDMA	Orthogonal Frequency Division Multiple Access

QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RSC	Recursive Systematic Convolutional
RSTBC	Rateless space-time block code
SC	Successive Cancellation
SCL	Successive Cancellation List
SE	Spectral Efficiency
SISO	Single-Input Single-Output
SIMO	Single-Input Multi-Output
UL	Uplink
UMTS	Universal Mobile Telecommunications System
VN	Variable Node
WiMAX	Worldwide Interoperability for Microwave Access

ABSTRACT

The goals of next-generation wireless networks are to prepare a different method of quality of service assurances to mobile users and applications. Customers expect wireless services to work as well as wired services anywhere and at any time, and they expect communication to be available and reliable at all times. Massive Multiple-Input Multiple-Output (MIMO) technology has the potential to handle orders of magnitude more wireless data traffic than current technologies. The primary concept of massive MIMO is that terminals are supported by the Base Station (BS) equipped with a huge number of antenna components that support numerous users over the same time-frequency resources. Future wireless communication systems must be able to enable important communications, which necessitates minimal latency and great reliability. The information transmitted is vulnerable to errors or faces incorrect detection at the receiver, reducing the reliability and efficiency of the system. This is because factors like fading, multi-path, and shadowing can have a greater impact on wireless channels. Massive MIMO systems can achieve improved reliability by increasing the number of antennas at base stations and utilizing spatial diversity. Channel coding is another method to enhance the reliability of data transmission of massive MIMO systems by reducing the Bit Error Rate (BER) of information. Redundancy bits are added to the information bits during channel coding. Different modulation schemes are used in this work, to compare the BER of a system without channel coding and with channel coding. By comparing Polar codes and Low-Density Parity Check (LDPC) codes, then it has been found that LDPC has a low BER. This thesis has been analyzed the BER of a massive MIMO system with channel coding and without channel coding. Assume the systems base station with perfect Channel State Information (CSI) and imperfect CSI acknowledgment. Channel coding is exponentially decreasing the BER of the system and the number of antennas also decreasing slightly. The result of the simulation shows BER of massive MIMO with channel coding is lower than without a channel coding system.

Key words: *Massive MIMO, channel coding, Bit Error Rate, perfect CSI, imperfect CSI*

CHAPTER ONE

1. INTRODUCTION

1.1. Background of the Study

The way we communicate has been fundamentally altered by wireless communication technologies. The days are gone when computers, phones, and Internet connections had to be wired and only used in specific locations. Thanks to the implementation of cellular wide area networks, satellite services, and local area networks, these communications services are now available wirelessly practically anywhere on Earth. Wireless connectivity has become as important to society as electricity, and as a result, new applications and services are being developed as a result of the technology. The streaming media revolution, in which music and film are provided via applications over the Internet, has already begun. Augmented reality apps, machine-to-machine links, and connected cars and homes have all taken the initial stages toward a fully networked world.

Since video fidelity is always improving, new must-have services are expected to emerge, and we are moving toward a networked world in which all electronic devices are connected to the Internet, the use of wireless data communication will surely expand in the near future. Expanding current wireless communications technology to satisfy ever-increasing demand and avoid data traffic congestion is a significant task. How to meet increasing service quality demands is another key issue. Customers want wireless services to perform as well wherever and whenever they need them, just as they expect infrastructure to be reliable and available at all times. Industrial and university researchers must break new ground in the development of breakthrough wireless network technologies to keep up with exponential traffic growth while also offering ubiquitous connectivity. Massive multiple-input multiple-output (MIMO) technology can handle several of times more wireless data traffic than present systems [1].

Massive MIMO is a type of MIMO system that has a great number of transmitting and receiving antennas. This technology employs numerous antennas to broadcast numerous data bits simultaneously. When compared to a single antenna system, several transmitting and receiving antennas will provide better data rates. Massive MIMO is a system in which a base station (BS) with a large number of antennas supports numerous users in the same time-frequency resource (collocated or distributed). With large antenna arrays at the BS, the channels arrive beneficial for most propagation conditions, i.e. the channel vectors between the users and the BS are (nearly) carefully orthogonal paired, and thus linear processing is almost the best [2].

Future wireless communication systems must be able to provide important communications, requiring minimal latency and great reliability. Massive MIMO is one of the technologies required to achieve this goal. By expanding the number of antennas at base stations and utilizing spatial diversity, massive MIMO systems can succeed enhanced reliability [3]. People's lives are increasingly reliant on communication systems, particularly for activities such as mobile communications and internet access. The transmission of data via Massive MIMO necessitates the interaction of multiple source-destination node pair numbers at the same time. Wireless channels, in comparison to wired communication, emit greater noise. This is because factors like multi-path, shadowing, and fading can have a greater impact on wireless channels. As a result, the bit error rate rises (BER). To limit the effects of such phenomena and enhance device efficiency, channel coding must be used [4].

In order to have a fast and error-free communication, channel coding is important. Redundancy bits are added to the message bits during channel coding. In most cases, redundant bits are utilized in channel encoding to aid in the detection of transmission faults. These bits don't carry any input data; instead, they include a few bits that are used to correct errors at the receiver. Error control coding techniques are effective for transmitting information through a communication channel with a low amount of errors. The channel code chosen must have outstanding Block Error Rate (BLER) efficiency for a specific range of block lengths and code speeds. Low processing complexity, minimal latency, low cost, and better flexibility are required for the coding scheme. In addition, to support higher data rates, reduced per-bit energy and increased area efficiency are needed.

The competing coding systems known as apply for large MIMO codes are convolutional codes, turbo codes, low-density parity-check (LDPC) codes, and polar codes [5]. Due to their superior performance, polar codes and LDPC codes have been chosen as channel codes in 5G communication scenarios. Polar codes have been proved to be a family of codes with limited encoding and decoding capacity in binary input discrete memoryless channels (BDMC), using the successive cancellation (SC) decoding schedule. Nonetheless, with modest code length, the SC decoder's BER performance degrades dramatically. A successive cancellation list (SCL) decoder is proposed in order to improve decoding performance, and the outcome is not dissimilar to that of the most advanced LDPC codes. In the Worldwide Interoperability for Microwave Access (WiMAX) Standard, the performance of polar codes using cyclic redundancy check aided sequential cancellation list (CA-SCL) decoding is superior to that of LDPC codes for equivalent code length and code rate [6].

Channel state information (CSI) is a term used in wireless communications to describe the known channel parameters of a communication link. This data illustrates how a signal travels from the transmitter to the receiver and denotes the cumulative effects of scattering, fading, and power loss as a function of distance. Channel estimation is the name of the method. Imperfect CSI occurs commonly in wireless communication systems due to the time-varying and random properties of both wireless channels and hardware components. The impacts of imperfect CSI reduce the system performance.

Modulation is the addition of data to a carrier signal in order to transfer data. Because digital modulation enables large information capacity and faster system availability while maintaining excellent communication quality, the use of various digital modulation techniques is growing in tandem with the growth and evolution of the digital communications sector. The simplest type of phase modulation is the BPSK digital modulation technique. Since the carrier phase only represents two-phase states in this scheme.

1.2 Statement of the Problem

The challenge of how to expand present wireless communications technology to meet the constantly increasing demand and avoid data traffic congestion is a critical one. Spectral efficiency, reliability, coverage, and energy efficiency are all major challenges in wireless communication. The information transmitted is vulnerable to errors or faces incorrect detection at the receiver, reducing the efficiency and reliability of the system. This is because factors like fading, multi-path, and shadowing can have a greater impact on wireless channels. One of the prospective wireless communication systems is Massive MIMO.

There are many techniques to solve this problem by using channel coding, increase the number of antennas. Channel coding is one of the methods to enhance the reliability and spectral efficiency of the massive MIMO by decreasing the bit error rate of the system. Redundancy bits are added to the message bits during channel coding. It plays an important role in improving the Quality of service of the massive MIMO system. There are many advanced techniques of channel coding for wireless communication for instance turbo code, convolutional, LDPC, and polar code. Polar codes and LDPC codes have been chosen as channel codes in 5G communication scenarios. Because both techniques have a low amount of error in a long message. In this work, evaluate the BER of a massive MIMO system with channel coding and without channel coding when the numbers of transmitters increase. Assume that the base station in massive MIMO systems has perfect and imperfect CSI.

1.3. Objective of the Study

1.3.1. General Objective

The main objective of this thesis is to analyze the BER of channel coding in massive MIMO systems.

1.3.2. Specific Objectives

- To analyze the performance of coded and uncoded data with different modulation in AWGN channel.
- To Evaluate the BER performance of massive MIMO with perfect and imperfect CSI.
- To Evaluate the BER performance of number of transmitter antennas without channel coding and single antenna with channel coding.
- To analyze the effect of the massive MIMO with channel coding and without channel coding.

1.4. Significance of Study

The key goals of near-future wireless communications include reliability, better data rates, more spectral efficiency, higher energy efficiency, and lower latency. Channel coding tends to enhance the reliability and spectral efficiency of the massive MIMO system by adding extra bits in a controlled fashion and is considered to be the most persuasive element of the communication system.

1.5. Scope of the Study

The channel coding in a massive MIMO system has an advantage. The advantage of a channel coding in massive MIMO system includes: increase the reliability, improvement of spectral efficiency, capacity enhancement and increase data rate. But, this thesis works only on the reliability of a massive MIMO system.

1.6. Main Contributions

This thesis purpose is to analyze the BER of Massive MIMO systems without channel coding scheme and with channel coding scheme. However, some of the differences between the previous work and the current work are underlined in the following points.

- LDPC code and Irregular polar code for massive MIMO is presented. This work evaluates the bit error rate of channel coding in massive MIMO systems with perfect and imperfect CSI.
- · Increase the number of base station antennas and channel coding is the way to increase reliability. Evaluate which one is best to perform from the two methods in terms of bit error rate.
- Evaluate the bit error rate (probability of error) when the number of BS antenna increases.

1.7. Thesis Organization

This thesis organizes into the following five chapters. Chapter 1: Background of the massive MIMO system and channel coding, statement of the problems, objectives, significance, scope of the research, and contribution.

Chapter 2: presents the literature review of the subject matter and it is more important than the other. It provides a thorough overview of the problem's background. It refers to what has already been researched by others and has relevance to the present day.

In chapter 3, describes the materials and methods followed in this research thesis

In chapter 4, presents the proposed results and discussions

Conclusions and future research work directions are offered at the end.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. MIMO Systems

Technology is continually improving. The original type of communication was point-to-point communication, sometimes known as a single input one output system (SISO). Then it progressed to SIMO (single input multiple outputs) and MISO (multiple input single output) communication systems, and finally to MIMO systems. Figure 2.1 shows the basics of SISO, SIMO, MISO, and MIMO systems. Since its introduction in the previous two decades, MIMO, or multiple-input multiple-output, is becoming more popular as a wireless technique that can deliver significant performance advantages over classic single-input single-output systems. It's an important technique that employs multiple antennas at the transmitter and/or receiver to significantly increase network speed, capacity, and coverage without requiring extra bandwidth or transmit power.

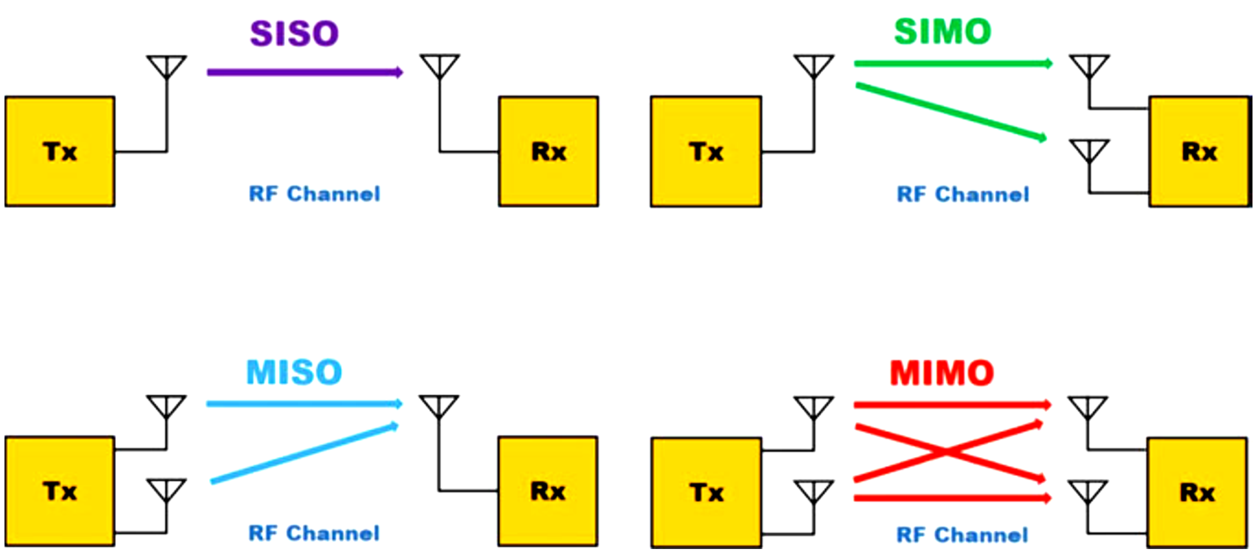


Figure 2. 1: Basics of SISO, SIMO, MISO, and MIMO systems [7]

Coding for MIMO Communication Systems provides a thorough review of the different developing coding approaches for MIMO communication systems. The fundamentals of wireless communications and fundamental concerns of MIMO channel capacity as well as space-time block and trellis coding methods. Other MIMO signaling techniques, such as spatial multiplexing, concatenated coding and iterative decoding for MIMO systems, and space-time coding for non-coherent MIMO channels, are also studied. Space time block code is a technique used in MIMO wireless communication systems to broadcast multiple copies of an information stream over varying numbers of antennas and to take use of the diverse received versions of the information to improve data transmission quality.

In point-to-point networks, multiple-input multiple-output (MIMO) has been extensively researched and understood to improve radio connection reliabilities through diversity and boost data rate through multiplexing. This has posed significant issues for antenna designers in terms of accommodating many antennas in a mobile terminal with limited space. However, recent MIMO developments have resulted in the transition from point-to-point single-user MIMO to multiuser MIMO (MU-MIMO), making it easier to put several antennas onto a compact mobile terminal. An MU-MIMO antenna system is a base station (BS) with several antennas that serves a group of single-antenna users at the same time, with the multiplexing gain shared by all users [8].

2.2. Advancements from MIMO to Massive MIMO

Massive MIMO takes things a step further, employing many antenna elements to simultaneously broadcast and receive streams of signals that are managed by advanced software, resulting in much-increased network capacity. The capacity increases from MIMO systems were so significant that many scientists began to investigate the effects of expanding the number of antennas beyond those found in standard MIMO systems. Massive MIMO technology emerged as a result of this. The high data rate demanded by consumers is the primary reason for expanding our communication systems' capacity. From time to time, this demand grows.

The main changes that were applied when advancing from MIMO to massive MIMO:

- The antennas that were used in MIMO systems were 2, 4, 8 . . . while the antennas that are used in massive MIMO systems are hundreds of antennas or even thousands of antennas.
- Massive MIMO systems are characterized by Number (BTS antennas) >> Number (users)
- The cellular other outstanding properties of massive MIMO systems come from the above characteristics of the massive MIMO systems. Currently, technologies are cell-centric

and this is not good if we are heading for a very high-speed connection. so, we need to move from cell-centric cellular networks to user-centric networks using the technology called beamforming.

Massive MIMO with beamforming enhances the end-user experience by significantly boosting network capacity and coverage while also decreasing interference.

2.3. Massive MIMO system

Massive MIMO is a larger-scale version of smaller-scale MIMO systems. Massive MIMO is a multiuser communications solution that makes a huge number of antenna elements to simultaneously serve multiple users, with the ability to select which users to receive at any one time. The most popular large MIMO idea implies that each user terminal has just one antenna and that the amount of antennas at the base station is substantially greater than the number of customers served. Massive MIMO's introduction has a huge impact on the R&D sector throughout the last decade. As a result, large MIMO has become a key characteristic in several future generation communication technologies, such as 5G below 6 GHz.

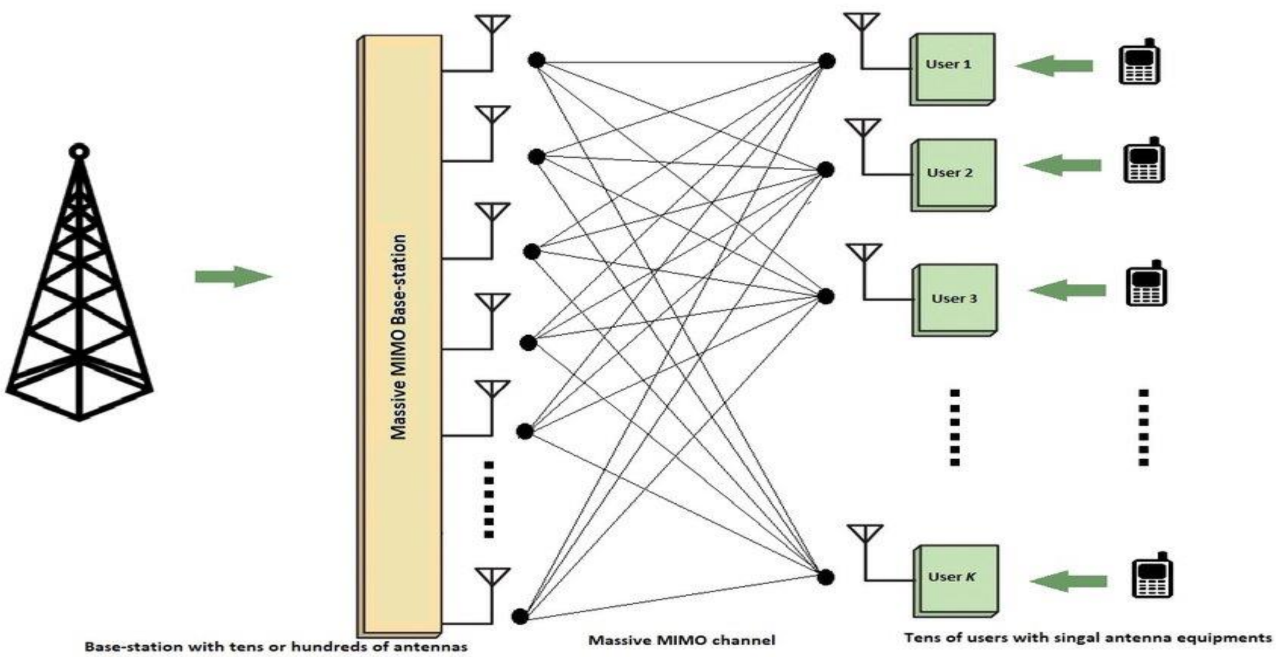


Figure 2. 2: Massive MIMO [8]

The majority of massive MIMO research focuses on high-rate mobile broadband challenges with huge data packets, making channel estimation and training a natural fit [8].

MIMO techniques will continue to play an important role in constantly increase wireless data speeds to the Gigabit range expected in the fifth generation (5G) standards. Over the next few years, demand for wireless communications is expected to rise. Massive MIMO systems are one possible solution for satisfying this demand. Massive MIMO, as a multiuser multiple antenna system, is a promising technique for next-generation wireless systems. Massive MIMO is a concept that asks for the construction of base stations with hundreds of antenna arrays to increase network capacity, improve reliability, and lower overall transmitted power. Massive MIMO is defined by the employment of a huge number of antennas, maybe hundreds or thousands, to transmit massive amounts of data to several users on the same time-frequency resources. Furthermore, massive antenna arrays can precisely guide emitted energy onto target receivers, thus reducing interference [9].

Massive MIMO represents a promising technique for future high-capacity connection requirements. It's the most attractive wireless physical layer technology right now, and it'll be a fundamental component of 5G networks. Massive MIMO is a form of MU-MIMO system in which there are a large number of BS antennas and users. Massive MIMO uses hundreds or thousands of BS antennas to simultaneously serve tens or hundreds of consumers in the same frequency resource.

2.3.1. Why Massive MIMO

The request for wireless throughput, communication reliability, and user density will continue to rise. Future wireless communication will necessitate new technologies that can simultaneously service a large number of users at high throughput. Massive MIMO is capable of meeting these requirements. Take, for example, uplink transmission. The same logic can be applied to downlink transmission.

Massive MIMO technology works by raising the spatial multiplexing gain and diversity gain by increasing the amount of antennas at the base station (BS), allowing users to receive signals from all of the antennas with relatively easy processing. The potential advantages of massive MIMO can be summarized as follows:

- Capacity and reliability: Massive MIMO improves diversity gain and thus connection robustness by preventing fading. Even when pilot contamination is present, capacity increases without limitations when multi-cell minimal mean square error (MMSE) precoding/combining and spatial channel correlation are applicable.

- Spectral efficiency: Massive MIMO enhances the spectral efficiency (SE) of cellular networks by spatial multiplexing a several number of user devices per cell. Multiple antennas allow for more spatial data streams, higher throughput, and higher multiplexing gain, all of which contribute to good spectral efficiency. Massive MIMO has been shown to have a 10 times higher overall spectral efficiency than standard MIMO, when tens of users are fed in the same time-frequency resources at the same moment.
- Energy efficiency: The transmitted power is inversely proportional to the amount of transmit antennas due to coherent combining. The transmit power will be drastically lowered as the number of transmit antennas grows. Where N_t the number of antennas, the power per antenna is should be $\propto 1/N_t$. Also, enhancing the number of transmit antennas while keeping the broadcast power constant, the throughput might be enhanced. Each antenna operates at milliwatts of power. As a result, system dependability and energy efficiency improved.
- Security enhancement and robustness improvement: In current wireless communication systems, man-made interference and purposeful jamming are important challenges. When there are a lot of antenna terminals, there are a lot of degrees of freedom, which can be used to cancel out intentional jammer broadcasts. Furthermore, because to beamforming, passive eavesdropping techniques are intrinsically resistant to gigantic MIMO systems. However, by utilizing the strong channel correlation in the vicinity of the user or the inadequacy of channel estimation, the eaves dropper can take countermeasures.
- Cost efficiency: Massive MIMO reduces the cost of system deployment by eliminating the need for bulky things like coaxial cables, which were previously used to connect BS components. Furthermore, instead of using numerous pricey high-power amplifiers, enormous MIMO employs a low-cost milliwatts amplifier. Furthermore, it has the ability to lower radiated power by 1000 times while substantially increasing data speeds.
- Signal processing: The signal processing is simplified since a huge amount of antennas remove interference, fast fading, uncorrelated noise, and thermal noise. Furthermore, when the channel replies from the base station to the user terminals are diverse, it is a favorable propagation environment (mutually orthogonal, i.e., the inner products are

zero). Non-orthogonal channel vectors, on the other hand, necessitate extensive signal processing to eliminate interference [8].

2.3.2. Massive MIMO Advantages

For many of the applications that future wireless networks are expected to have, reliability is becoming increasingly important. Massive MIMO is a technique that could help these systems is more reliable. One target for this is a phenomenon known as channel hardening, which states that as the amount of antennas in a system grow the variability in channel gain in the time and frequency domain decrease. Massive MIMO has the potential to improve reliability by utilizing an unprecedented amount of spatial diversity by deploying a huge amount of antennas at the base station. Additional benefits include increased spectral and energy efficiency [10].

The demand for more efficient communications and wireless throughput will continue to rise. As a result, new technologies are required to serve several users with high throughput at the same time. These requirements can be met with Massive MIMO. To obtain the array and multiplexing gain, favorable propagation circumstances and optimal processing at the BS are required. These benefits can also be accomplished utilizing linear processing with massive MIMO rather than the respectable low-dimensional point-to-point MIMO with relatively sophisticated processing algorithms. In fact, due of the low number of large numbers, if the number of BS antennas in massive MIMO is extended to a very big number, the channel becomes advantageous. As a result, linear processing is practically ideal for massive MIMO. Simple linear processing can thus be used to achieve array and multiplexing benefits. Additionally, the throughput may constantly be enhanced by increasing the number of users and BS antennas.

2.3.3. Uplink (UL) Data Transmission

UL data transmission fills a portion of the coherence interval. The BS in the UL receives transmitted data from all K terminals using the same frequency-time resource. The BS uses channel estimates and linear combination techniques to define the signals transmitted from all terminals.

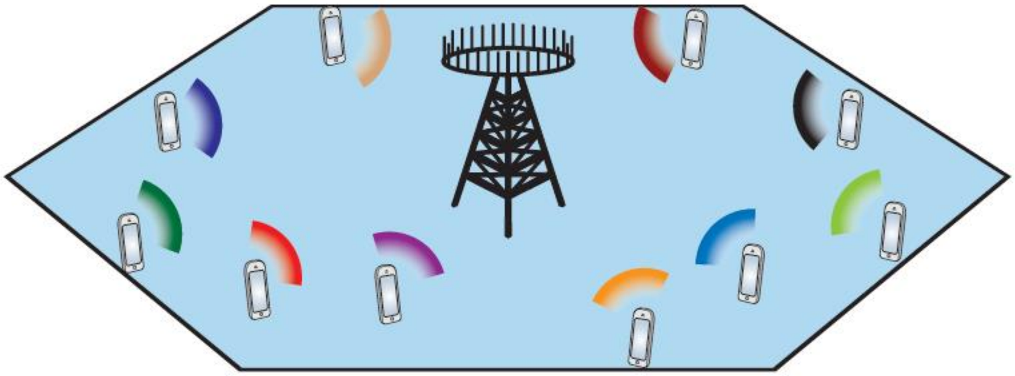


Figure 2. 3: Uplink in multi-user MIMO [11]

2.3.4. Downlink Data Transmission

The BS transmits signals from the same time-frequency resource to all K users in the downlink. More exactly, the BS uses its channel estimates in conjunction with the symbols intended for K users to generate M precoded signals, which are subsequently delivered to M antennas [2].

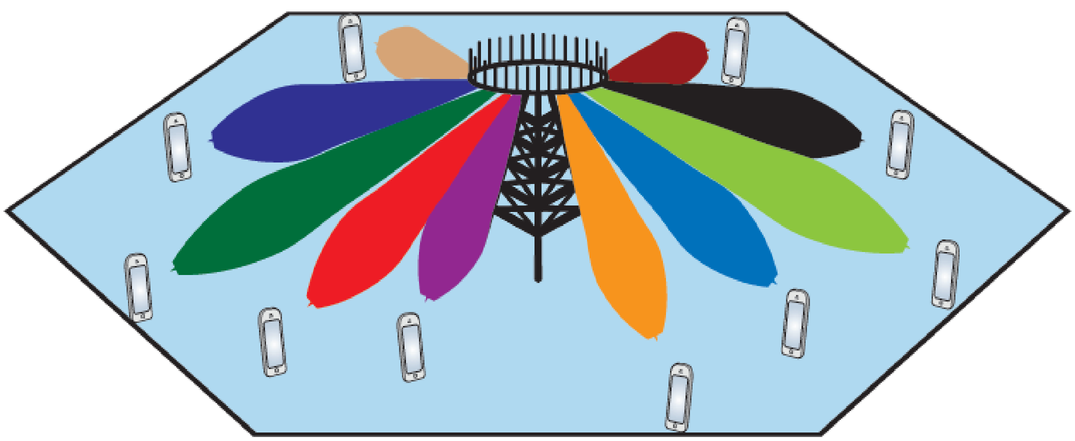


Figure 2. 4: Downlink in Multi-user MIMO[11]

2.3.5. Perfect CSI and Imperfect CSI

What exactly does it mean to have a perfect channel? Is a perfect channel defined by the absence of noise or by the use of pilot symbols to assess the channel? It is the estimation, not the channel, which is perfect. As a result, "perfect channel estimation" denotes that the receiver has a perfect understanding of the fading coefficients. Of fact, this is only true in a simulation; any real-world system does poor estimation, and estimated channel coefficients are only roughly equivalent to actual coefficients.

CSI is a word used in wireless communications to describe the known channel parameters of a communication link. This data illustrates how a signal travels from the transmitter to the receiver and denotes the cumulative effects of scattering, fading, and power loss as a function of distance. Channel estimation is the name of the method. The CSI allows transmissions to adjust to present channel circumstances, which is critical for accomplish dependable high-data-rate communication in several antenna systems [12]. At the receiver, CSI must be estimated, quantified, and fed back to the transmitter. As a result, the CSI of the transmitter and receiver may differ. The CSI at the transmitter and the CSI at the receiver are commonly abbreviated as CSIT and CSIR. Transmitters, like perfect CSI, In order to take advantage of favorable channel conditions; they modify their power and coding mode in response to channel observations.

Imperfect channel state information (I-CSI) occurs commonly in wireless communication systems due to the time-varying and random properties of both wireless channels and hardware components. The impacts of imperfect CSI reduce the system performance. Transmitters, like perfect CSI, adjust their power and coding mode in response to channel observations in order to take advantage of favorable channel conditions. However, Channel outages occur when the rate set turns out to be too aggressive for the actual channel realization due to the inaccuracy of imprecise CSI. From a practical standpoint, it is widely understood that a channel back-off mechanism is required to enforce the use of more conservative coding modes in order to mitigate the negative effects of outages caused by faulty CSI [13].

2.4. Channel Coding Schemes

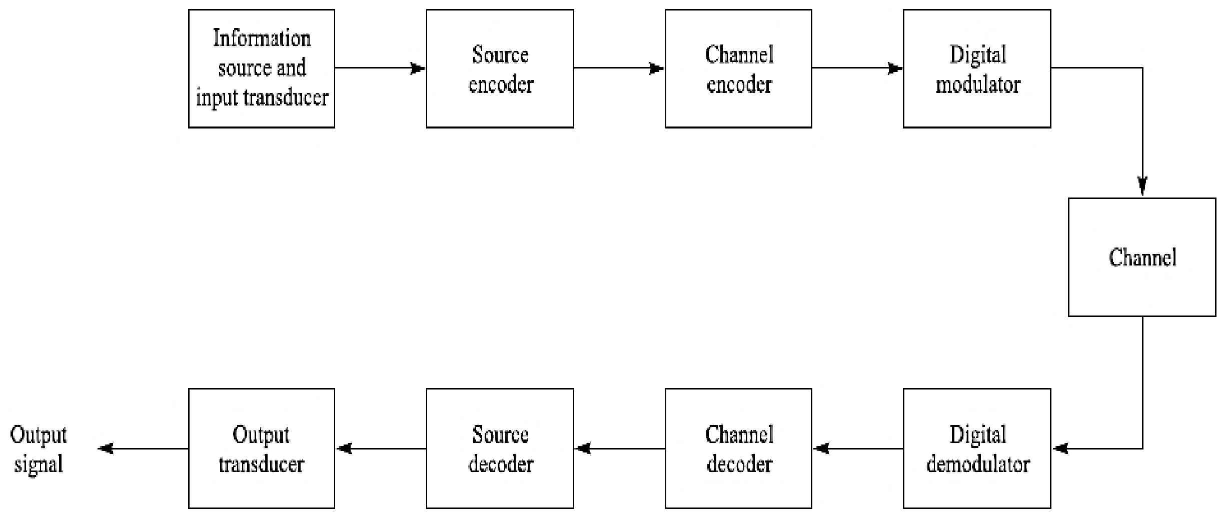


Figure 2. 5: Basic elements of a digital communication system [14]

The functional diagram and basic components of a digital communication system are shown in Figure 2.5. As the source output, you can use an analog signal like audio or video, or a digital signal like a computer output that is discrete in time and has a finite number of output characters. The messages from the source are transformed into binary digits in a digital communication system. The source output (message) would be represented by as few binary digits as possible in an ideal world. Source encoding or data compression is the process of efficiently converting the output of an analog or digital source into a series of binary numbers.

The source encoder of this basic communication device effectively converts the input signal, whether analog or digital, into a series of binary digits (removing redundancy). The channel encoder then provides redundancy in a controlled manner to lessen the receiver's impact of communication channel failures. As a result of the added redundancy, the system's reliability is improved after that, the modulator modulates the binary sequence from the channel encoder, transforming the bits into an electrical signal that can be sent over any communication channel.

The communication channel is the physical medium that relays the signal from the transmitter to the receiving antenna. From the waveform received by the receiving antenna at the receiving end, the digital demodulator reconstructs the binary bits transferred from the channel encoder to the modulator. Using the redundancy added and the encoder's codebook, the channel decoder would next attempt to rearrange the original information bits. Finally, the source decoder translates the binary bits to the digital or analog signal they came from. The received signal may be merely a rough approximation of the original signal due to source encoder and source decoder distortion, as well as channel decoding faults [14].

Channel Coding

Information is transmitted through wireless networks by interacting with a large number of source-destination node pairs at the same time. When compared to conventional communication, wireless channels have higher noise. This is because fading, multi-path, and shadowing will have a greater impact on wireless channels. As a result, the bit error rate rises (BER). Channel coding technology must be used to lessen the impact of such phenomena and increase system performance. An amount of redundancy bits will be added to the message bits in channel coding. In most cases, redundant bits are included in channel encoding to aid in the detection of faults that occur at the same time of transmission. These bits do not carry any input data; instead, they contain only a few bits that are used to repair errors at the receiver. Error control coding techniques are effective for transmitting information through a communication channel with a low amount of errors [15].

It's one of the key approaches that allow for near-capacity operating. Large possibilities for error detection and repair can be accomplished by adding uniform redundancy at the transmitter (encoding) and using it at the receiver (decoding). Because of their good performance and the minimal complexity of state-of-the-art implementation, these systems were chosen as 5th generation wireless communications contenders (5G) [16]. The physical layer's channel coding and modulation play important roles in achieving high spectral efficiency. Channel coding is essential for ensuring rapid and Data transmission takes place in an imperfect channel environment, therefore error-free communication is impossible. Although several coding schemes with large block length capacity are available, many of them do not consistently function well across a vast variety of block lengths and code rates. Convolutional, turbo, LDPC, and polar codes are the four coding systems considered [17].

2.4.1. Turbo Coding

Claude Berrou suggests Turbo Codes as a new class of convolutional code that is able to make close to Shannon Limit in 1993.Turbo codes are a recursive approach for channel coding in wireless communication technology. In the Turbo encoding approach, two identical recursive systematic convolutional (RSC) codes are utilized with simultaneous concatenation [18].

Turbo codes can be found in a diverse set of uses, including deep space communications, 3G/4G mobile communication in the Digital Video Broadcasting standards, and Long Term Evolution (LTE) standards, and Universal Mobile Telecommunications System (UMTS) because of their performance with a minimal probability of error within a 1dB fraction of the Shannon limit and low complexity (DVB). While it is used in 3G and 4G, eMBB's performance specifications for all code rates and block lengths may not be met, as the realization complexity for higher data rates is too high. Furthermore, an error level is found in the BER turbo code. Due to the interleaving and iterative process, high decoding complexity is frequently coupled with significant latency, which is one of the main drawbacks of turbo decoding [19].

2.4.2. Convolutional Coding

Elias first proposed convolutional coding in 1955. Convolutional codes are error correction codes that have been widely embraced by several standards due to their numerous benefits, such as low-complexity encoding, the ability to do simple rate-adaptation via puncturing, and hardware-friendly decoding algorithms, among others. Unlike many modern coding systems, their bit-error performance does not improve as message length increases, making them unsuitable for long-distance transmission. With maximum-likelihood (ML) decoding, they nevertheless perform comparably for small message lengths [19]. The input information bits are encoded bit-by-bit (stream) in such a way that the input bits are convolved with (or slide against) defined polynomials, hence the name "convolutional". A single codeword is translated into the whole input stream using the convolutional code. The encoded bit is based on the previous bit's information as well as the current bits. The Viterbi algorithm is often used for decoding. Low-rate codes, such as convolutional codes, tend to correct more errors due to their redundant bits. This means the communication system can transmit at a higher data rate while operating at a lower transmission rate and accepting greater noise and interruption. As a result, the code is more energy-efficient [20].

The Convolutional Encoder and Viterbi Decoder blocks are used in this model to simulate a tail-biting convolutional code. Terminating a convolutional code's trellis is an important element in packet-based communications. Tail-biting convolutional coding is a trellis termination technique that eliminates the rate loss associated with zero-tail termination in exchange for a more sophisticated decoder. A finite-state machine generates a convolutional code, which has states that are dependent on the present and previous inputs. The encoder normally begins and finishes in an all-zero state. The encoder may be brought back to an all-zero state with a tail of zeros, and the decoder is more successful when it knows the starting and ending states. The encoder's states are considered to begin in an all-zero state when using the zero tailing approach. The encoder is no longer in an all-zero state once all of the incoming information sequences have been processed. Zeros equal to m, i.e., the amount of memory elements, are fed into the encoder to bring it back to an all-zero state. As a result, there is a loss of fractional rate [21].

2.4.3. LDPC Coding

In 1962, Robert Gallager constructed the Low-Density Parity Check Code (LDPC). LDPC is a very effective coding method for error correction and BER reduction in noisy multipath fading communication channels. The chance of knowledge loss can be reduced with LDPC in a way that is as close to Shannon's as possible. The sparse parity check matrix H can be used to define LDPC codes as (m, n) m rows and n columns, in other ways M check nodes and N variable nodes or bits [22].

The parity check's matrix H is made up of (n,k) n code words and k information bits, with $k = n - m$. $R = k/n$ is the code for the Rate R code. The Tanner graph is commonly used to show an LDPC code and its decoding process. A Check Node (CN) represents each row, and a Variable Node (VN) represents each column (VN). The links between the CNs and VNs are represented by the “1”s in the matrix. Turbo and LDPC codes were tested against one another in a variety of use cases and applications because they both perform well. Turbo codes, on the other hand, have a high encoding complexity but a low decoding complexity, and LDPC codes have a high encoding difficulty but a low decoding complexity [23].

2.4.4. Polar Coding

Polar codes were the first class of constructive channel codes introduced by Arkan, and they were shown to reach the symmetric (Shannon) capacity of a binary input discrete memory less channel employing a low-complexity decoder, namely a successive cancelation (SC) decoder. Polar coding works by splitting two alike binary-input channels into two distinct channels, one better and one worse than the original binary-input channel. By repeating such a pairwise polarizing operation on a set of $N = 2^n$ independent uses of a binary-input channel, a set of 2^n bit channels of different qualities, in terms of the reliability in communicating a single bit, can be obtained for any given integer *n*. When n is huge, some of these bit channels are quite close to being perfect (i.e., error-free), while others are practically unusable (i.e., totally noisy). The goal is to provide data to the receiver across nearly flawless channels while setting the useless channels' input to known fixed or frozen values (e.g., zero). The input bits to the essentially worthless and nearly perfect bit channels, respectively, are frozen bits and non-frozen (or information) bits. Only the non-frozen sections carry information. A polar code's performance is directly influenced by the information set, or the set of non-frozen bit locations.

In a binary input discrete memoryless channel (BDMC) with a successive cancellation (SC) decoding schedule, polar codes have been found to have low encoding and decoding capacity. Nonetheless, with modest code length, the SC decoder's bit error rate (BER) performance degrades dramatically. In order to improve decoding performance, a continuous cancellation table (SCL) of the decoder is proposed, and the outcome is not dissimilar to that of the most advanced LDPC codes. The effectiveness of the polar codes employing the cyclic redundancy check aided sequential cancellation list (CA-SCL) decoding is superior to that of the LDPC codes in WiMAX Standard for the same code length and code rate.

Polar codes with cyclic redundancy check-aided (CRC-aided) successive-cancellation list (SCL) decoding can achieve the best BER results while reducing complexity. Polar codes with CRC-aided list decoding outperformed state-of-the-art low-density parity-check (LDPC) codes for short block lengths. As a result, polar code, very efficient and dependable channel code, has a wide range of potential applications in wireless communication [24].

The length of the CRC code and its generator polynomial affect the performance of polar codes concatenated with CRC code as their outer code, as well as list decoding and CRC code detection (or list-CRC decoding). The structure of CRC codes, on the other hand, has received little attention to date. The CRC codes used in the majority of the previous research are 16 bits or greater, and their length has been decided through trial and error. Otherwise, for simulation reasons, perfect error detection capacity is assumed, provided optimal CRC codes are used. However, if the code's block length is short, the relative redundancy joined with CRC codes takes precedence, reducing the concatenated code's overall efficiency [25].

2.5. Digital Modulation Techniques

The process of adding information to a carrier signal in order to transport data is known as modulation. Because digital modulation enables greater information capacity and faster system availability while maintaining excellent communication quality, the use of various digital modulation techniques is growing in tandem with the digital communications industry's expansion and evolution. In recent times, the growth of multimedia facilities for mobile wireless communication has contributed to a great advancement in the field of wireless communication.

Digital modulation technology is one of the commonly used techniques that enable digitized data to be transmitted or transmitted through analog radio frequency channels. For uninterruptible communication, the data transmission rate should be maximal. But with high rates, the risk of error is higher [26]. The process in which the receiver filters out the information given by the transmitter is known as demodulation. $s(t) = A(t)\cos(2\pi f_c t + \phi)$ is the formula for a radio signal, where A is the amplitude, f_c the carrier frequency, and ϕ the phase. The signal can be modulated to transmit information by adjusting these characteristics. Amplitude Shift Keying , Frequency Shift Keying, and Phase Shift Keying are the three main digital modulation techniques based on the changing of these parameters [27].

2.5.1. Binary Phase Shift Keying (BPSK)

The BPSK digital modulation schemes is known as the easiest kind of phase modulation since the carrier phase only represents two-phase states in this scheme. All digital modulation techniques are less efficient than BPSK. As a result, BPSK is employed to achieve high bit rates while consuming less power. The phase of the sinusoidal carrier is modified relevant to the data bit to be conveyed in binary phase-shift keying.

The data stream controls the BPSK modulator, which is essentially a two-positional switch. The 0º phase is enabled by the high level of data, while the 180º phase is enabled by the low level of data. The main benefit of Binary Phase Shift Keying is that it is a good modulation format for downlink data transmission systems since it produces high data rates and low power consumption. When compared to QPSK modulation, which is nearly double the complexity of BPSK modulation, BPSK modulation is simpler to design and less complex to implement. The BPSK digital modulation technology is commonly employed in high-speed data transport applications. When compared to the BASK modulation technique, it is simple to execute and provides a 3dB power improvement. A serialized numerical signal modulates phase with two possible states of the intermediate frequency in BPSK modulation [28].

2.5.2. M-ary QAM

QAM is a modulation technology that allows the amplitude to change with phase. ASK and PSK signals are combined in QAM signaling. It can also be seen as a two-dimensional ASK. It's a type of non-constant envelope method that, with the same average signal strength, can achieve greater bandwidth efficiency than M-PSK. When the amount of bits in a symbol, m = log2 (M), is even, square QAMs are the most widely utilized constellations. Non-square QAM constellations, such as rectangle and cross shape constellations, are utilized when an odd number of bits per symbol is required for transmission. Rectangular QAM constellations are sub-optimal in that they do not maximize the spacing between constellation points for a given energy. Non-rectangular QAMs are more difficult to modulate and demodulate than rectangular QAMs. Cross QAM, on the other hand, is usually the better choice in terms of energy efficiency, as it has lower average and peak energy than rectangular QAM [26].

2.6. Related Works

Performance Analysis of Coded Massive MIMO-OFDM Systems Using Effective Matrix Inversion studied on [29] derive the bit error rate and pairwise error probability (PEP) for massive MIMO-OFDM systems for different *M*-ary modulations based upon the approximate noise distribution after channel equalization. The PEP is used to obtain the upper-bounds for convolutional coded and turbo coded massive MIMO-OFDM systems for different code generators and receive antennas.

LDPC Coding Used in Massive-MIMO Systems are worked on [31] a comparison study between the classical systems and the LDPC coded system will be performed, in order to stress the improvements in particular cases. This research focuses on the use of LDPC coding in the implementation of a Massive-MIMO system, ranging from simple MIMO systems and increasing the amount of antennas at the receiver.

Design a coded massive multiple-input multiple-output (MIMO) system using low-density parity-check (LDPC) codes and iterative joint detection and decoding (JDD) algorithm on [32] employing low complexity detection. The factor graph representation of the LDPC coded massive MIMO system is used to define the message updating rule in the JDD. The proposed LDPC codes and the proposed JDD approach result in a lower bit error rate in coded massive MIMO systems than standard LDPC coded massive MIMO systems. This work used LPDC code and iterative joint detection and decoding (JDD) algorithm.

Irregular Polar Coding for Massive MIMO Channels in [33] a fresh polar code family, whose polarization units are irregularly pruned to drastically decreases the computational complexity in both encoding and decoding. It's well known that irregular codes with specified degree distributions outperform regular codes in the setting of LDPC codes. To account for irregularity, relaxed polar codes were developed, in which some polarization units are deactivated when the bit-channels are sufficiently good or bad. They then use wireless massive MIMO communication channels to test the suggested polar codes. This method is by different way polarization units are irregularly shortened.

The performance of Manchester source coding in an uplink LDPC channel coding OFDM-based massive MIMO system [30] proposed a Massive multiuser MIMO system with Manchester source coding, LDPC channel coding and OFDM used by multiple users, when the number of antennas at the receiver varies between 8 and 12. Analyze the quality of the information that reaches the BS using extensive Monte Carlo Matlab simulations in terms of BER versus signal-to-noise ratio (SNR) for pseudorandom (PN) spreading codes, which spreads the OFDM modulated signal with or without Manchester encoding.

Rateless space-time block code (RSTBC) for massive MIMO systems present on [9]. They show how to implement rateless space-time codes in huge MIMO broadcasts over wireless erasure channels. Due to a different of factors like interference, channel fading, or antenna element failure, data may be lost or not decoded at the receiver in such channels. Show that RSTBC ensures the system's reliability in such situations, even when the data loss rate is 25% or higher. Traditional fixed-rate codes fail to operate effectively in such a very lossy channel, especially when channel state information is not available at the transmitter. Unlike typical channel codes, the rateless code has no fixed rate, and most of the available literature is an extension of the fountain codes to the erasure channels.

LDPC Coded Massive MIMO-OFDM System is studied on [34]. For a massive MIMO-OFDM system with 16-QAM modulation, the performance of ZF, MMSE, and AMP equalizers is studied. Those studies focused on the performance of a linear equalizer in a Massive MIMO-OFDM system using LPDC coding.

BER analysis of channel coding techniques for 5G networks [35] proposed system mainly focuses on two channel coding techniques namely convolutional codes and LDPC codes. The LDPC codes are feasibility with 5G wireless communication is evaluated in terms of BER performance and complexity and it is compared with the coded and uncoded convolutional codes.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. Introduction

In this thesis, related secondary sources of data such as different books in channel coding, previous researcher's studies, different Institute of Electrical and Electronics Engineers (IEEE) articles, journals, development in 5G cellular technology in general, and basics of massive MIMO, in particular, were revised. Based on the inputs retrieved from a review of related literature and the statement of the problem in mind, the methodology of this study is designed as follows;

3.2. Materials

In this research work, software such as MATLAB/R2019b is used. MATLAB is the computing software that consists of technical toolboxes and Simulink.

3.3. Methods

3.3.1. System Design

- Generate input data
- Prepare a mathematical model for calculation the channel encode and decode
- Prepare a mathematical model for calculating the bit error rate of channel coding in single transmitter antenna system
- Prepare a mathematical model for calculating the bit error rate when the number of transmitter antenna increase
- Prepare a mathematical model for calculating the bit error rate perfect and imperfect CSI

3.3.2. Simulation Methods

- Outline simulation workflow
- Simulation for coded and uncoded data.
- Simulation for evaluation perfect and imperfect CSI.
- Simulation for evaluation channel coding in massive MIMO system.
- Perform reliability evaluation analysis whether the target requirement is achieved or not.

3.4. Mathematical model of Channel Coding in Massive MIMO

Massive-MIMO systems can be coded using a variety of methods, including turbo codes, LDPC coding, and polar coding. Random codes can be used to attain the channel capacity required. In Massive-MIMO systems, LDPC and polar are advantageous because they perform well in terms of Shannon's limit, which is an important consideration. We decided to investigate the performance of LDPC and polar in Massive-MIMO systems because the 3GPP standards group is debating whether the turbo code used in 4G should be replaced in 5G with the LDPC or polar code.

The analog messages generated by the source are transformed to digital representation before being transferred. In a digital communication system, the source's messages are translated into a series of binary digits. The source output (message) would be represented by as few binary digits as possible in an ideal world. Source encoding or data compression is the process of efficiently turning the output of an analog or digital source into a series of binary values. The source encoder of this basic communication device effectively converts the input signal, whether analog or digital, into a series of binary digits (removing redundancy). The channel encoder then provides redundancy in a controlled manner to lessen the receiver's impact of communication channel failures.

3.4.1. Channel Encoder

The channel encoder's objective is to add redundancy to the broadcast signal, in this case, to allow for the correction of errors produced by noise during transmission at the receiver. Error-control coding is a method of encoding that is used to protect against channel errors. There are two generally ways for reducing errors in electronically transferred data. Forward error control (FEC) is one way Information bits are secured against errors in this method by transmitting extra redundant bits, which can be used by the decoder to detect where errors occurred and how to correct them if they occur during transmission. The automatic repeat request (ARQ) method is the second approach of error control. This method involves adding redundant bits to the transmitted data, which the receiver uses to detect errors. A request for a repeat transmission is then sent by the receiver. The amount of redundant bits required to only identify an error, as in the ARQ system, is typically much smaller than the number of redundant bits required for both detecting and fixing a mistake, as in the FEC system. The first method is applied in our case.

I. LDPC encoder

LDPC code is a linear error-correcting code with a sparse parity check matrix H, meaning that each row and column contains fewer nonzero elements. Irregular and regular LDPC codes are the two types of LDPC codes. Gallager codes are binary LDPC codes in their original state. H is mostly quite huge, but the density of nonzero elements is extremely low. LDPC code of length n, or indicate as an (n, W_c, W_r) LDPC code. Thus, every information bit is corresponding with W_c parity checks, and each parity-check bit is involved with W_r information bits. For a regular code, we have $(n-k)W_r = nW_c$ thus $W_r < W_c$. If every rows are linearly independent, the code rate is $(W_r - W_c)W_r$, otherwise it is k/n. Typically, $W_c \geq 3$.

The parity check matrix H Tanner graph is a bipartite graph. It has check nodes (CN) equal to the amount of rows of H and bit nodes or variable nodes (VN) equal to the amount of columns of H. If $H_{ji} = 1$, i.e. if variable i involve in the j^{th} parity-check constraint, and then check node j is connected to variable node i.

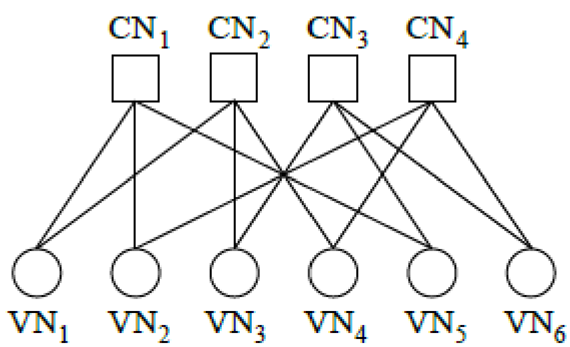


Figure 3. 1: Tanner graph of the example [16]

If a parity check matrix's Tanner graph contains no loops, this decoding can be done fastly. Unfortunately, because LDPCs have loopy graphs, the algorithm must be iterated again until it finds a solution. By selecting Tanner graphs with longer girths, the impact of girth on LDPC code performance can be reduced. Longer girths, on the other hand, aren't useful for finite length codes. Because a girth of 6 is sufficient, girth 4 must be removed.

For LDPC codes, Gaussian elimination in modulo-2 arithmetic is used to construct a generator matrix G from the parity check matrix H for coding purposes. The matrix G is applicable in all encodings of messages because it is constructed just once for a parity check matrix. 1-by-n code length C is involved as

$$C = [b \quad : \quad m] \tag{3.1}$$

where b is the n − k by 1 parity vector , and *m* is *k* by 1 message vector similarly, the parity check matrix *H* is subdivided as

$$H^T = \begin{bmatrix} H_1 \\ \vdots \\ H_2 \end{bmatrix} \tag{3.2}$$

where H_1 is a square matrix of dimensions $(n-k)\times(n-k)$ and H_2 is a rectangle matrix of dimensions $k\times(n-k)$ transposition symbolized by the superscript T is used in the dividing of matrix *H* or ease of representation [21].

$$[\mathrm{b}:\mathrm{m}]\begin{bmatrix} \mathrm{H}_1 \\ \mathrm{M} \\ \mathrm{H}_2 \end{bmatrix} = 0 \tag{3.3}$$

$$\mathrm{bH}_1 + \mathrm{mH}_2 = 0 \tag{3.4}$$

The vectors m and b are related by

$$\mathrm{b} = \mathrm{mP} \tag{3.5}$$

where P is the coefficient matrix. For any non-zero message vector m, the coefficient matrix of LDPC codes fulfill the prerequisites

$$\mathrm{PH}_1 + \mathrm{H}_2 = 0 \tag{3.6}$$

$$P = H_2 H_1^{-1} \tag{3.7}$$

The generator matrix of LDPC codes is denoted by

$$G = [P \quad : \quad I_k] = [H_2 H_1^{-1} \quad : \quad I_k] \tag{3.8}$$

where I_k is the k by k identity matrix The code word can be generated as

$$C = mG \tag{3.9}$$

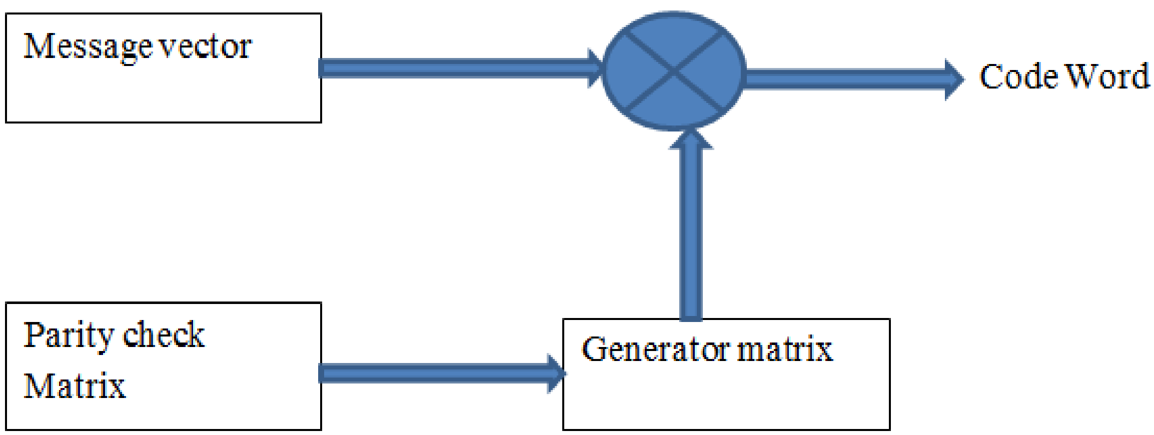


Figure 3. 2 Block diagram of LDPC encoder

II. Polar encoder

Polar codes are reported to be able to fill a binary discrete memoryless channel to capacity. This can only be done when the block size is large enough. The encoding and decoding complexity is low, and these codes can be successfully decoded. The fundamental elements for both uplink and downlink are polar encoding kernel, the CRC encoder, and rate matcher. The standard method for CRC encoding is used. The CRC bits, on the other hand, serve a dual purpose in polar coding. They are first applying for error detection in order to keep the false detection rate (FAR) below a specific threshold $P_{FAR} \approx 2^{-nFAR}$. Second, they are also applying for error correction at the end of SCL decoding with a target list size $L = 2^{nL}$, to remove CRC-failed decoding pathways from the list. The CRC length is set $n_{crc} = n_{FAR} + n_L$ for both uplink and downlink control channels, the target list size of eight (i.e., $n_L = 3$) is implicitly presumed in the requirements of 5G NR [36].

A transformation that produces N “synthetic” bit-channels from N independent copies of a binary-input discrete memoryless channel is known as channel polarization (B-DMC). The new synthetic channels are then "polarized," which means that they can each convey a single bit with various degrees of reliability, i.e., with varying chances of being correctly decoded. If

N is large enough, the synthetic channels' mutual information is either near to 0 (totally noisy channels) or close to 1 (absolutely noiseless channels), resulting in channels with high capacities. Polar codes are a simple way to build polarized channels, with a proportion of noiseless channels that approaches the capacity of the original B-DMC. The discovery of the polarization phenomenon of the matrix, commonly referred to as the basic polarization kernel, is the mathematical foundation of polar codes.

$$G = \begin{bmatrix} 1 & 0 \\ 1 & 1 \end{bmatrix} \tag{3.10}$$

For example, this matrix enables the encoding of a two-bit input vector $u = [u_1 \quad : \quad u_2]$ into code word $x = [x_1 \quad : \quad x_2]$ as $x = u.G$, namely having $x_1 = u_1 \oplus u_2$ and $x_1 = u_1$.

Polar codes are created by concatenating many fundamental polarization kernels, resulting in a cascade response that speeds the polarization of synthetic channels while reducing encoding and decoding complexity. This concatenation generates a channel transformation matrix of the form $G_N = G^{\otimes n}$, denoted by the n-fold Kronecker product of G, and that can be recursively calculated

$$G_N = \begin{bmatrix} G_{N/2} & 0 \\ G_{N/2} & G_{N/2} \end{bmatrix} \tag{3.11}$$

while $n \to \infty$ this construction creates channels that are either perfectly noiseless or completely noisy, The polarization of the synthetic channels may be incomplete for smaller values of n, resulting in somewhat noisy intermediary channels. By construction, polar codes only allow for code lengths that are powers of two, in the form $N = 2^n$; on the other hand, the code dimension K, i.e. the total amount of bits of data sent, can take any arbitrary value. The purpose of a (N, K) polar code's code design is to find the K best synthetic channels, i.e. the channels with the maximum dependability, and use them to transfer the information bits.

The dependability of each synthetic channel can be assessed, and the K information bits can be assigned to the most reliable channels, whose indices make up the code's information set I. The remaining $N-K$ indices form the frozen set $F = I^C$ of the code, and the own channels are “frozen”, not carrying any information. An (N, K) polar code is denoted by its channel transformation matrix $G_N = G^{\otimes n}$ and its information set I . The generator matrix of the code is given by the sub-matrix of G_N composed by the rows whose indices are stored in I. However, the recursive structure of G_N allows minimizing the encoding complexity with the introduction of an auxiliary input vector u of length N. This input vector $u = [u_0, u_1, u_2, ..., u_{N-1}]$ is generated by assigning $u_i = 0$ if $I \in F$, and storing the information bits in the remaining entries [37]. Code word $x = [x_1, x_2, ..., x_{N-1}]$ is then calculated as

$$x = uG_N \tag{3.12}$$

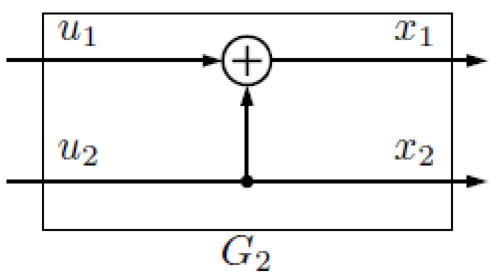


Figure 3. 3 Encoding scheme n=2 [38]

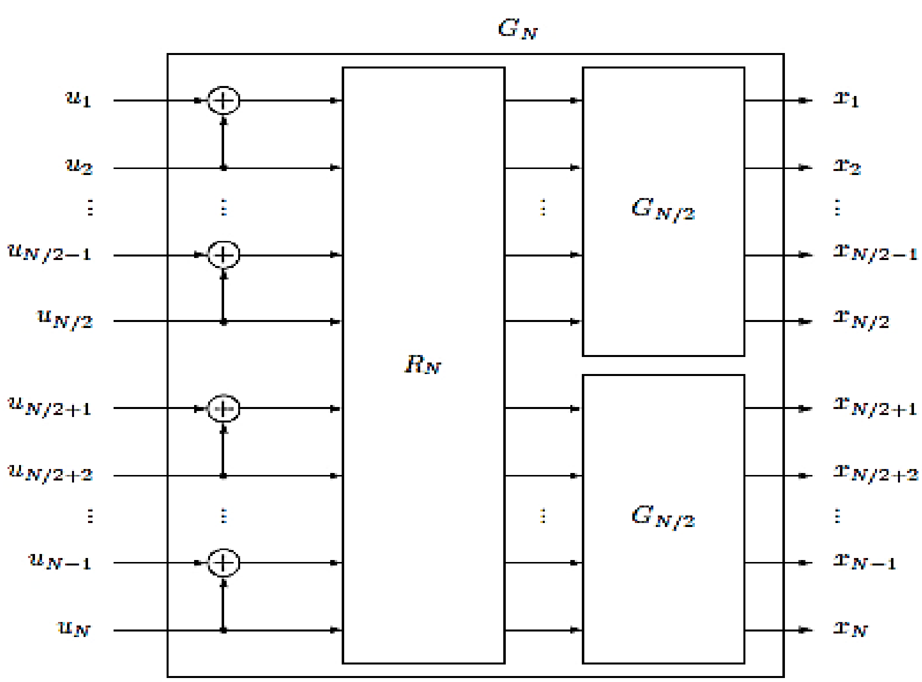


Figure 3. 4 Recursive construction of G_N from two copies of $G_{N/2}$ [38]

3.4.2. Digital Modulation

Digital modulation is the method of encoding a digital data signal into the transmitted signal's amplitude, phase, or frequency. The encoding technique has an impact on the transmitted signal's bandwidth and robustness to channel degradation. In general, a modulation technique encodes many bits into a single symbol, and the symbol transmission rate determines the transmitted signal's bandwidth. The simplest form of phase modulation is BPSK digital modulation, which uses only two-phase states for the carrier phase. All digital modulation techniques are less efficient than BPSK. As a result, BPSK is employed to achieve high bit rates while consuming less energy. In binary phase-shift keying, the phase of the sinusoidal carrier is changed based on the data bit to be conveyed.

BPSK modulation is calculated as

$$x = (1 - 2 * codeword) \tag{3.13}$$

where x is the modulated data and codeword is the encoded data

QAM is a modulation technology that allows the amplitude to change with phase. ASK and PSK signals are combined in QAM signaling. It can also be seen as a two-dimensional ASK. It's a type of non-constant envelope method that, with the same average signal strength, can achieve greater bandwidth efficiency than M-PSK. When the amount of bits in a symbol, m = log2 (M), is even, square QAMs are the most widely utilized constellations.

Additive White Gaussian Noise channel

The channel serves as a conduit between the UE and the BS. There are a variety of channel models that have been examined. In order to design and build a wireless communication system, you must have a basic understanding of the many types of channel models and their properties. When modeling networks, channel models are used to see how the system design functions in different settings and under different conditions.

The AWGN channel model in communications employs a single impediment: a linear addition of broad band or white noise with a constant spectral density given in watts per hertz of bandwidth and a Gaussian amplitude distribution. The model does not account for interference, fading, nonlinearity, frequency selectivity, or dispersion. There is no need to be concerned about the distortion that a carrier-modulated telecommunication signal may face when traveling over specific propagation media because it does not suffer from fading. However, before considering the other events, it develops fundamental and tractable mathematical models that can be utilized to get insight into the underlying behavior. Wideband Gaussian noise includes the thermal vibrations of atoms attached to antennas, often known as thermal noise, shot noise, and black body radiation from warm things such as the earth.

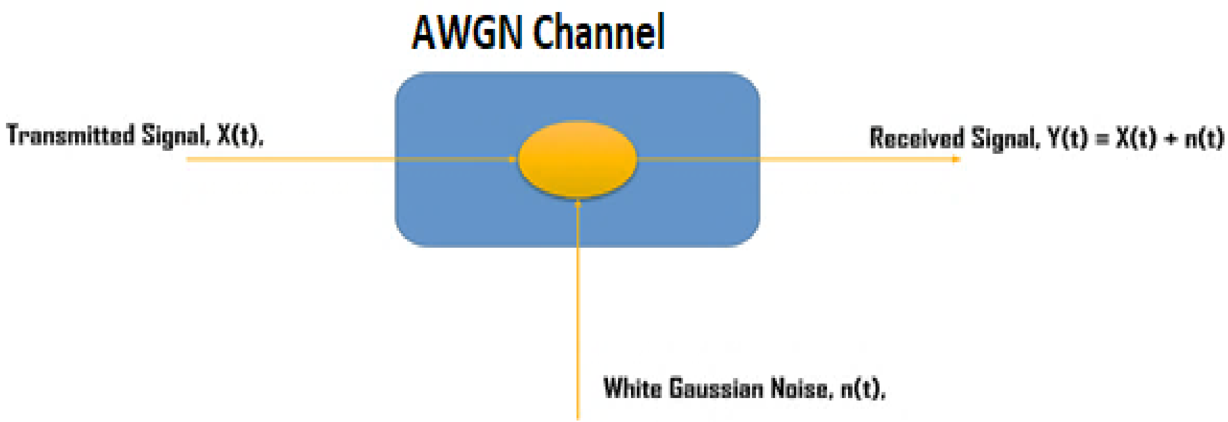


Figure 3. 5: AWGN channel [39]

3.4.3. Channel Decoder

The process of turning received messages into codewords of a specific code is known as decoding. There have been a variety of approaches to mapping messages into codewords.

I. LDPC decoder

Iterative decoding methods that iteratively transfer messages back and forth between the bit and check nodes until the operation is terminated are known as message passing algorithms. The concept of belief propagation underlies soft-decision decoding. The sum-product algorithm is a message-passing soft decision technique. These probabilities are given as log-likelihood ratios in sum-product decoding. The matrix for a binary variable is represented by a single value using log-likelihood ratios (LLR). The sum-product algorithm is a soft decision message-passing procedure, similar to the bit-flipping method. The primary difference between SPA and the bit flipping method is that each decision is represented by information bit probabilities [40].

Important terms in the algorithm are:

- $P_i = P_r(C_i = 1/Y_i)$
- q_{ji} is a message sent by the message node C_i to the check node f_j. Every message contains always the pair $q_{ij}(0)$ and $q_{ij}(1)$ which stands for the values of belief that Y_i is a 0 or a 1
- r_{ji} is a message sent by the check node f_j to the variable node C_i. Again there is a $r_{ji}(0)$ and $r_{ji}(1)$ that to point out the number of belief that Y_i is a 0 and a 1.

The following steps involved in the sum-product algorithm

Step 1: Messages are sent from all message nodes q_{ij} message. $q_{ij}(1) = P_i$ and $q_{ij}(0) = 1 - P_i$

Step 2: The response messages of the check nodes are calculated by the check nodes r_{ji}

$$r_{ji}(0) = 1/2 + 1/2 \prod_{(i\varepsilon v_j/i)} (1 - 2q_{ij}(1)) \tag{3.14}$$

and

$$r_{ji}(1) = 1 - r_{ji}(0) \tag{3.15}$$

Step 3: the message node updates its response message to the check node using

$$q_{ji}(0) = k_{ij}(1 - p_i) \prod_{j'\varepsilon c_i/j} (r_{j'i}(0)) \tag{3.16}$$

and

$$q_{ji}(1) = k_{ij}(p_i) \prod_{j'\varepsilon c_i/j} (r_{j'i}(1)) \tag{3.17}$$

Constant k_{ij} are chosen in such a way as to guarantee

$$q_{ij}(0) + q_{ij}(1) = 1 \tag{3.18}$$

At this point, the message nodes also update their current estimation $C_i^{'}$ of their message .those done by calculating by the probabilities for 0 and 1 and selecting for the bigger one.

$$Q_i(0) = k_i(1 - p_i) \prod_{j\varepsilon c_i} (r_{ji}(0)) \tag{3.19}$$

And

$$Q_i(1) = k_i(p_i)\prod_{j\varepsilon c_i}(r_{ji}(1)) \tag{3.20}$$

Step 4: C_i is 1 if $Q_i(1) > Q_i(0)$ .otherwise C_i is 0

II. Polar Decoder

a) Successive Cancelation Decoding

Arikan proposed the sequential cancelation decoding (SCD) technique for polar code decoding. The SCD butterfly diagram is identical to the encoder butterfly diagram. The likelihood ratios (LRs) in the decoding butterfly diagram propagate from right to left. Upper and lower nodes refer to the nodes in the butterfly's upper and lower corners. Computing LRs at each node is used to achieve correct decoding. As a suboptimal decoding method, polar coding is often used with SC decoders. Even though certain decoding methods have improved in recent years, SC decoding remains an important aspect of polar coding. The decoder should know the knowledge of u_1^{i-1} when decoding u_i . Generally, the decoder only knows the amount of frozen bits $\{u_j, j\varepsilon A^c\}$ from the frozen set A^c in advance. As the SC decoder decodes bits continuously, at least provides an estimate of u_1^{i-1} when decoding u_i. Consider a polar code with the parameter vector *(N, K, A,* uA^c *)*, where *N* is the code length, *K* stands for a number of information bits, *A* is the information set and uA^c is the frozen bits vector. From right to left, the probabilities move in the opposite manner. The likelihood ratio is defined as

$$L_N^{(i)}(y_1^N, u_1^{i-1}) = \frac{W_N^{(i)}(y_1^N, u_1^{i-1}/u_i = 0)}{W_N^{(i)}(y_1^N, u_1^{i-1}/u_i = 1)} \tag{3.21}$$

$$u_{i=}\begin{cases}0, if\ L_N^{(i)}\ (y_1^N & , u_1^{i-1} \geq 1\\ 1, otherwise\end{cases} \tag{3.22}$$

and the steps of SC decoding algorithm are explained as follows.

Step 1: For the rightmost side variable, channel observations were used to set it up.

For $i = 1, 2, 3, ..., N$ $\quad L_1^{(1)}(y_i) = w(y_i/u_i = 0)/W(y_i/u_i = 1)$

Step 2: This step decodes the first bit u_1. If u_1 is a frozen bit set to 0. In other words, by computing f and g, the likelihood ratios are updated and the required LR is obtained. If LR >

1, set $u1$ to 0 or If LR < 1, u_1 is to be set to 1. If LR = 1, u_1 is to be set to 0 or 1 with equal probability.

Step 3: In this step, the second bit u_2 is decoded. The procedure is similar to step 2, only the value is utilized to compute g functions in order to produce the LR value. is calculated using the obtained LR value.

Step 4: This step decodes the remaining bits $u_3,...,u_N$ in the order by making use of the estimated previous bits values

b) Successive Cancelation List Decoding

It has been shown that the sequential cancelation list (SCL) decoder outperforms the SC decoder. As shown in the figure, SCL uses a list (L) of successive cancelation decoders in simultaneously to generate a list of candidate decisions and select the most likely word from the list.

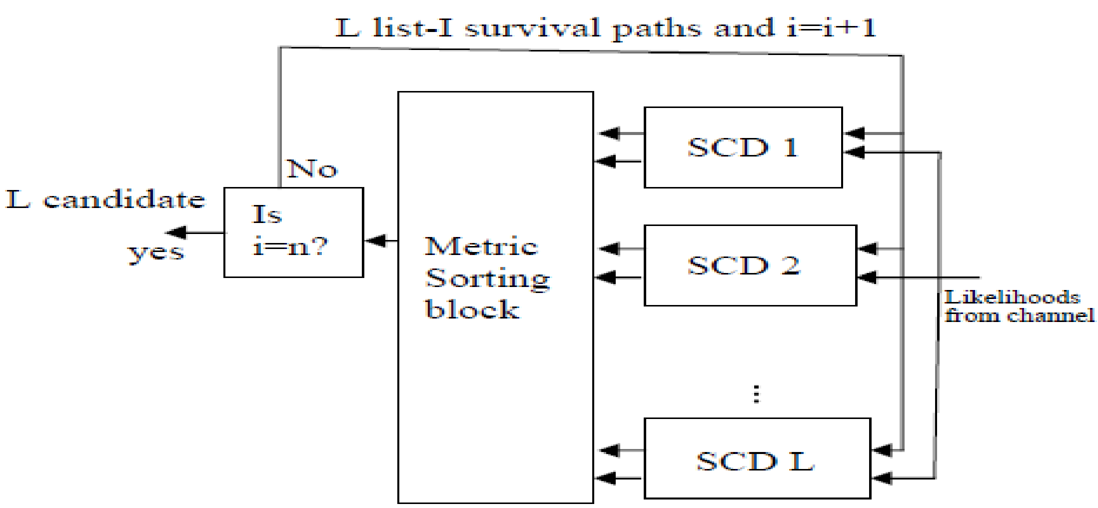


Figure 3.6: Successive cancelation list decoder [21]

3.4.4. Calculate the Bit Error Rate

Bit error rate, block error rate, and flexibility are all factors to consider while evaluating channel coding. In wireless communication, the bit-error rate (BER) is an important concept. The bit error rate is the percentage of received bits in a digital data transfer that are incorrect, i.e., the percentage of bits that have been changed due to channel effects, synchronization issues, or device failures [27].

For calculating single input single output probability of error

$$P_e = NRBE/TTB \tag{3.23}$$

where NRBE represents the number of received bits with errors and TTB represent the total number of transferred bits

I. Perfect CSI

Perfect CSI is a word used in wireless communications to describe a communication link's known channel parameters. This data illustrates how a signal travels from the transmitter to the receiver and represents the cumulative impact of fading, scattering, and loss of power as a function of distance. The downlink channel state information should be provided back to the base station to increase spectral efficiency and reliability of a huge MIMO. Due to the huge number of antennas on the BS, however, it is difficult to implement feedback in real applications. The massive MIMO system has attracted more and more attention recently since it can average out the effects of the thermal noise when the number of antennas goes to infinity another benefit of a massive MIMO system is that by shifting the direction of the array in the downlink, a tremendous array gain can be achieved [41]. Energy per bit to noise power spectral density ratio and signal to noise ratio of massive MIMO system given defined as [42]:

$$SNR_{(M-MIMO)} = M_t N_t * SNR \tag{3.24}$$

$$P_e \propto 1/M_t \tag{3.25}$$

The probability of error Massive MIMO is

$$p_{e(M-MIMO)} \propto 1/M_t * P_e \tag{3.26}$$

where M_t the number of base station antenna is, N_t is the number of receiver antenna, P_e is the probability error of a single antenna and $p_{e(M-MIMO)}$ is the probability of error of channel coding in Massive-MIMO. Assume the probability of error for perfect channel state information

$$p_{e(M-MIMO)} = 1/M_t * P_e \tag{3.27}$$

II. Imperfect CSI

To gain the benefits, accurate CSI is required at the transmitter. Noisy channel estimations cause imperfect CSI, which may also be outdated due to a delay in sending the CSI to the transmitter. Imperfect CSI is frequent in wireless communication systems because of the time-varying and random features of wireless channels and hardware components. Assume the probability of error imperfect channel is

$$P_e = 1/\sqrt{M_t} \tag{3.28}$$

$$SNR_{(M-MIMO)} = \sqrt{M_t} * SNR \tag{3.29}$$

$$E_b / N_{o(M-MIMO)} = \sqrt{M_t} * E_b / N_b \tag{3.30}$$

$$p_{e(M-MIMO)} = 1/\sqrt{M_t} * P_e \tag{3.31}$$

CHAPTER FOUR

4. RESULTS AND DISCUSSIONS

In this chapter presents the simulation result of proposed system to fulfill the specific objective of the research. It has been simulated the performance analysis for different cases such as,

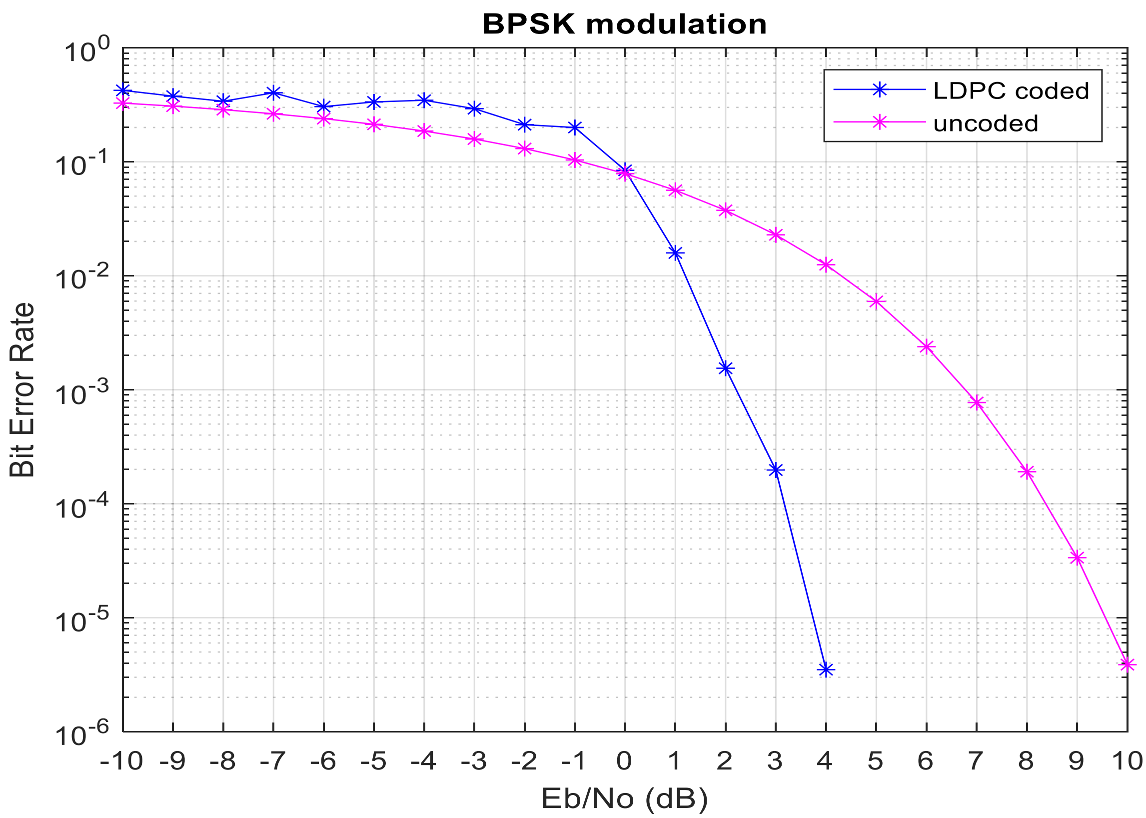
- Uncoded and coded data in AWGN channel
- LDPC and polar code
- Coderates
- Perfect and imperfect CSI without channel coding
- Uncoded in number of antenna and Coded in single antenna
- Coded and uncoded in perfect and imperfect CSI

4.1. Uncoded and Coded Data in AWGN Channel

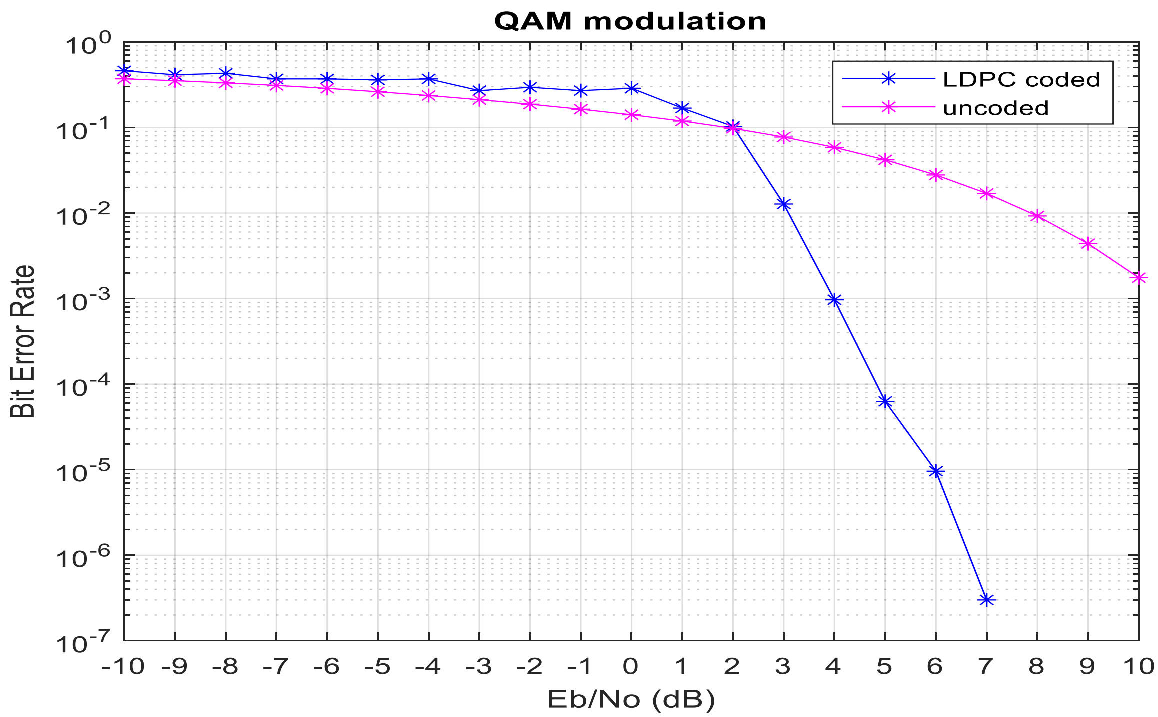
Figure 4.1 and Table 4.1 presents a BER performance comparison of LDPC coded and uncoded data by using BPSK, QAM, and 8-QAM modulation when the amount of information bits K is 100 in single antenna. The results are taken from -10dB to 10dB with an increment of 1dB. As the figure shows, at very low Eb/No (dB), the performance of uncoded data has low bit error rate than coded one. However, as the Eb/No(dB) increases, the bit error rate of coded data decreases exponentially while uncoded data shows only a slight change in higher-order modulation. By using BPSK modulation, the bit error rate of coded data has considerable improvement compared to QAM modulation. This again certifies that, at worst environmental conditions, it is advisable to use low order modulation like BPSK instead of the high order modulation scheme. Also using the BPSK modulation scheme decreases the bit error rate substantially when compared to QAM and 8-QAM. On the other hand, low order modulation has a low bit error rate compared to high order modulation.

Table 4. 1 Comparison of uncoded and coded data in AWGN channel

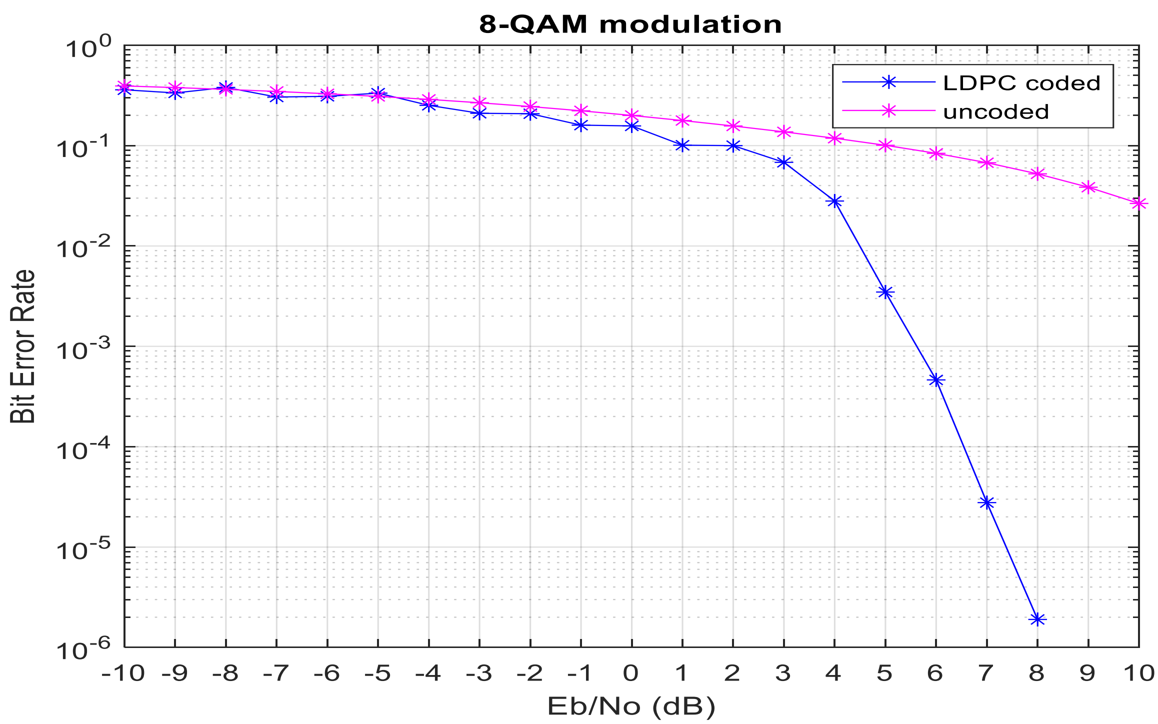
Input data = 100 bits in AWGN channel						
Eb/No(dB)	BPSK modulation BER		QAM modulation BER		8-QAM modulation BER	
	Uncoded data	LDPC coded data	Uncoded data	LDPC coded data	Uncoded data	LDPC coded data
-2	0.15	0.2	0.2	0.3	0.3	0.2
2	0.04	0.0016	0.1	0.1	0.17	0.1
4	0.013	$3.5*10^{-6}$	0.06	0.001	0.13	0.028



(a)



(b)



(c)

Figure 4. 1 Eb/No (dB) vs Bit Error Rate (a) BPSK (b) QAM (c) 8-QAM

4.2. LDPC and Polar Code

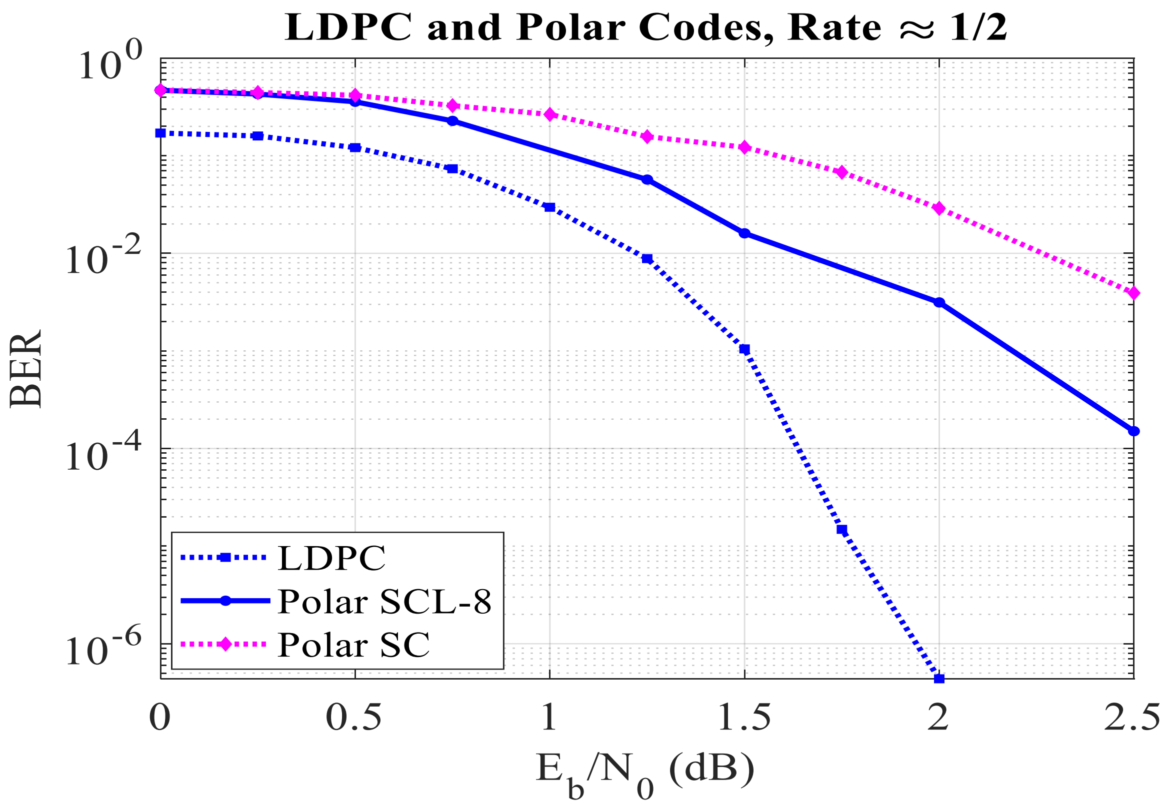


Figure 4. 2: The comparison between LDPC and polar code in terms of Eb/No vs BER

Table 4. 2 Comparison of LDPC and polar code

Input data = 512 bits and codeword = 1024 bits			
	LDPC code	Polar code with SC	Polar code with SCL
Eb/No(dB)	1	1	1
BER	0.029668	0.26523	0.21408

Figure 4.2 and Table 4.2 presents the performance of BER of LDPC code and polar code when the codeword length is 1024 and the code rate is 1/2. The results are taken from 1dB to 2.5dB with an increment of 0.5dB. The modulation scheme of binary phase-shift keying is simulated.

For polar code with SCL decoding algorithm, the list size is simulated for L = 8. As shown in the figure, the polar code with SC is inferior to the polar codes with SC with list decoding and LDPC in terms of error-correcting performance. LDPC code outperforms polar code with SC and SCL.

4.3. Coderate Analysis

Figure 4.3. indicates the BER of the two code rates are plotted in terms of energy per bit to noise power spectral density ratio (Eb/N0) in dB for the rate =1/2 and rate=1/4 for information length =256. The simulated channel coding scheme is polar code with successive cancellation decoder. When the number of Eb/No (dB) increases the BER is decreased exponentially. From the simulation result, the bit error rate of the lower code rate is low and when increasing the number of code rate bit error rate also increases. On the other hand, increase the redundancy bit into data transmission will decrease the bit error rate.

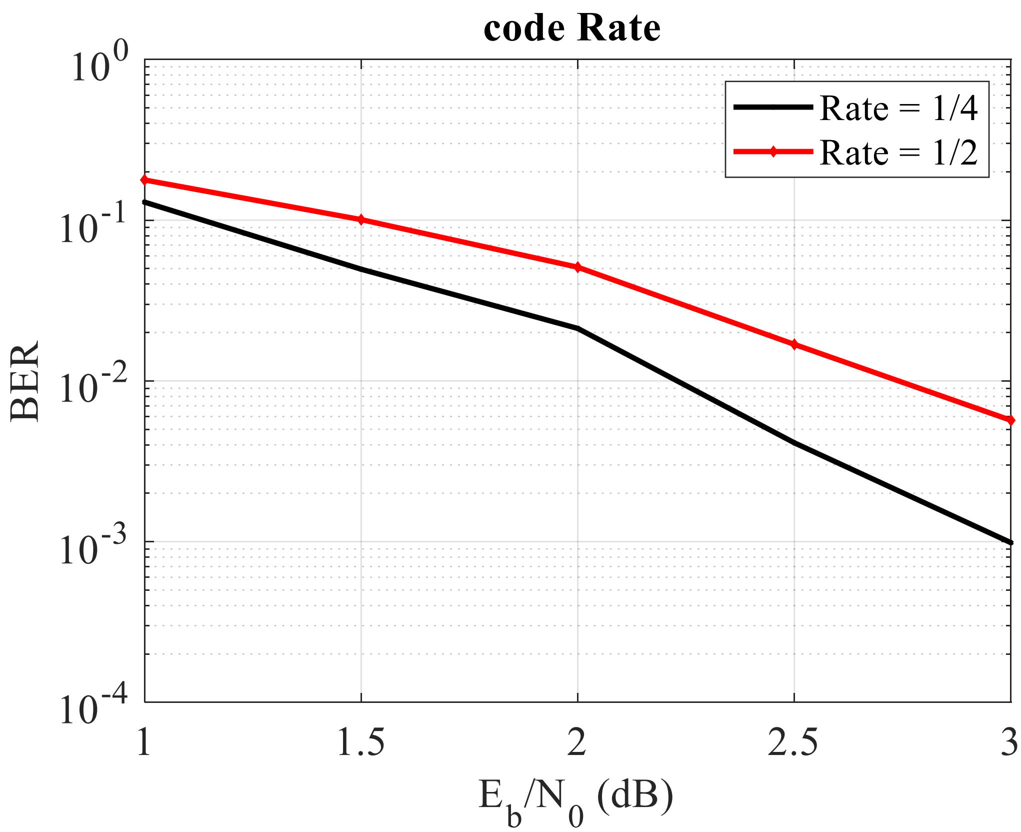


Figure 4. 3 The comparison between coderate =1/2 and 1/4 in terms of Eb/No (db) vs BER

4.4. Perfect and Imperfect CSI in Number of Antennas

Figure 4.4 indicates the bit error rate with regard to the number of Eb/No (dB) different values of transmit antenna. As the figure shows, It can be seen that, in four different numbers of transmit antennas, the bit error rate decreases when the number of Eb/No (dB) increases. From the simulation result, we can notice that bit error rate decrease by increasing the number of base station antennas. The number of antenna N=256 has a lower bit error rate compared to others. This is because of the number antenna increase the number of redundancy bit is increased.

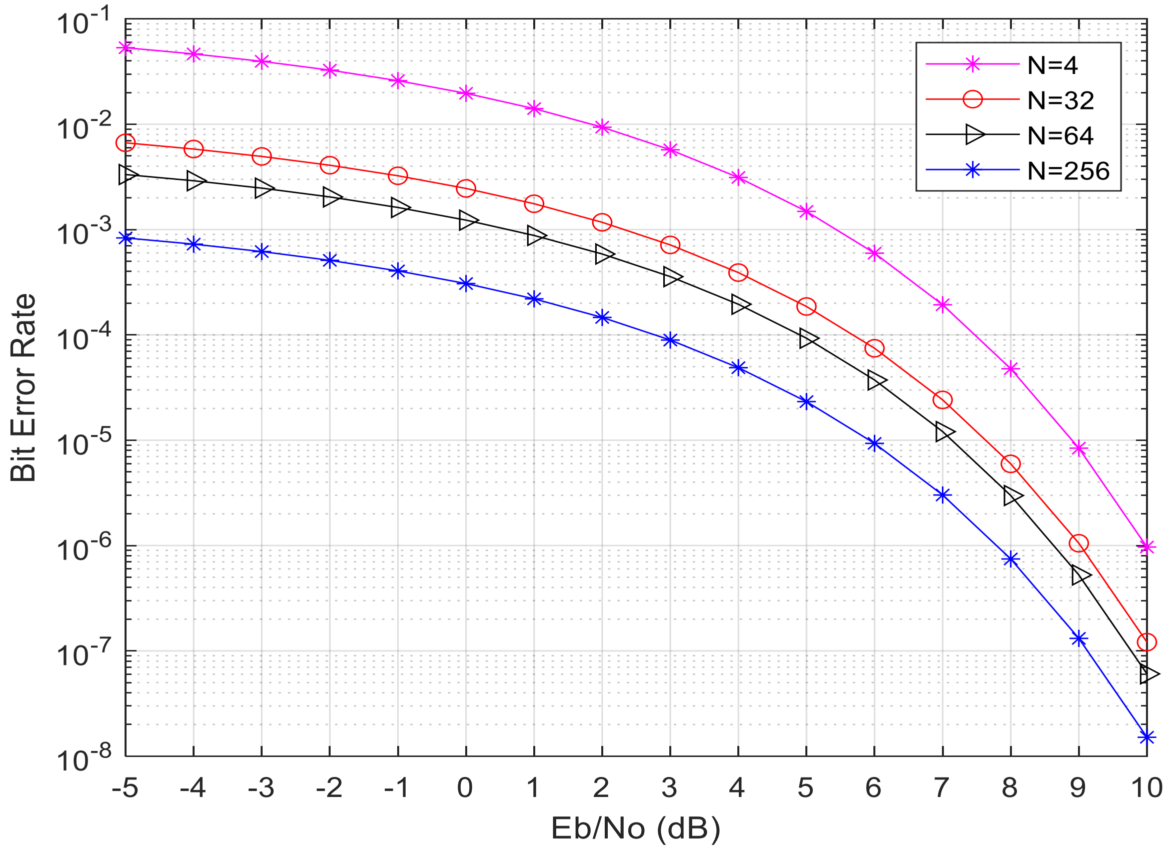


Figure 4. 4 Eb/No (dB) vs BER at transmit antennas =4, 32, 64, 256

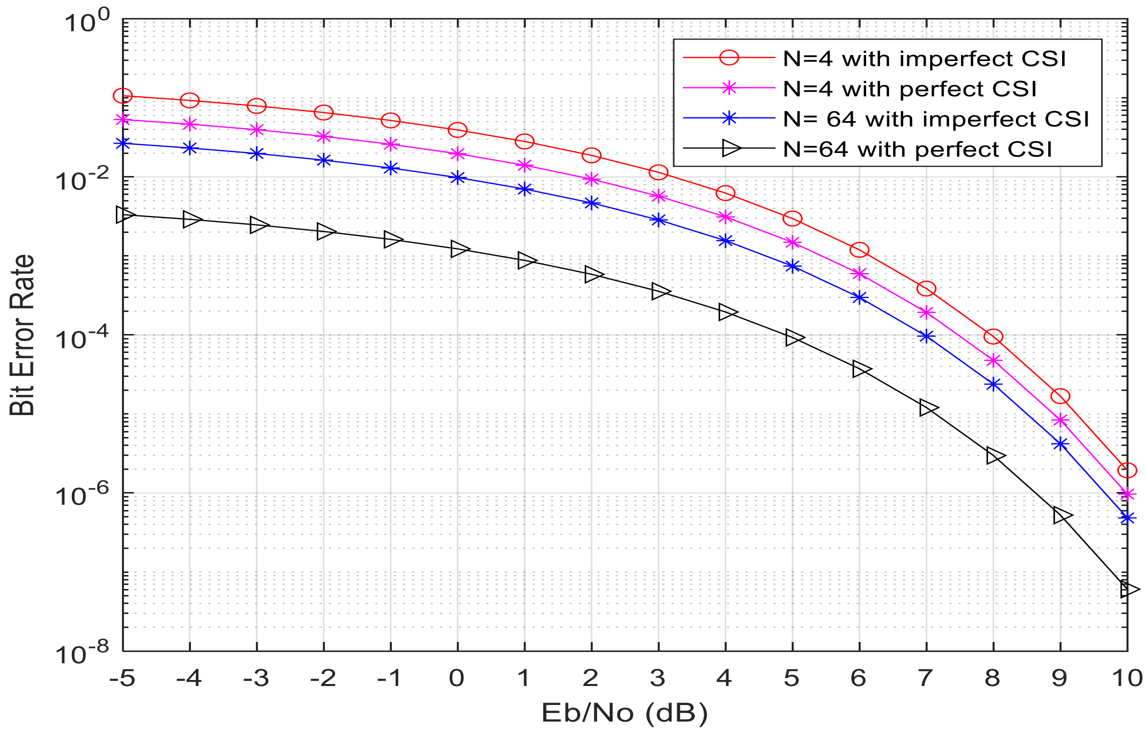


Figure 4. 5 Perfect and imperfect channel at transmitting antenna = 4 and 64

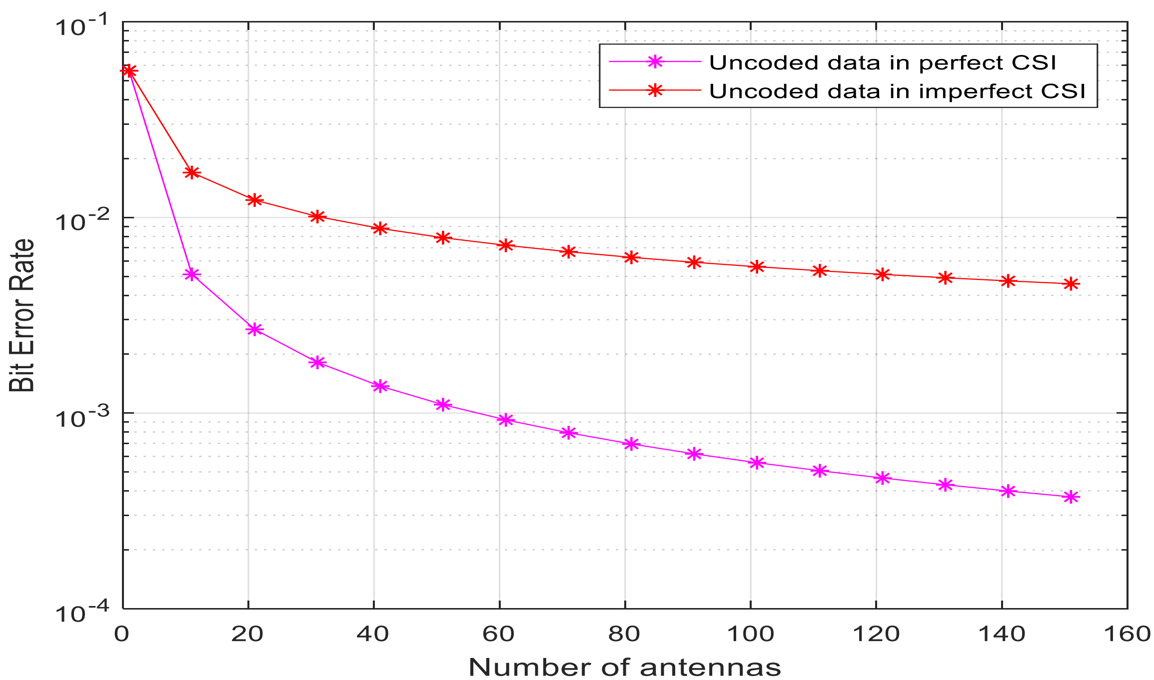


Figure 4. 6 Bit error rate Vs number of the antenna in perfect and imperfect channel

Table 4. 3 comparison of perfect and imperct CSI

Input data = 100 bits in BPSK modulation		
Number of antennas	Uncoded data in perfect channel BER	Uncoded data in imperfect channel BER
1	0.056	0.056
20	0.00268	0.012

Figure 4.5 presents a BER performance comparison of the perfect and imperfect CSI by using BPSK modulation when the number of antenna N= 4 and N= 64. The results are taken from -5dB to 10dB with an increment of 1dB. From the simulation result, we notice that the perfect CSI has a low bit error rate because the transmitter (or base station) knows channel properties of a communication link.

Figure 4.6 and Table 4.3 show a performance comparison between uncoded data in a perfect and imperfect CSI with respect to bit error rate vs different numbers of transmit antenna by using a fixed number of EbNodB =1. The result is taken from 1 to 160 the number of transmitter antenna with increment 10 antennas. As the number of transmitter antenna increases the bit error rate logarithmically decreases. Compared to uncoded data with imperfect channels the perfect channel is outperforming.

4.5. Uncoded in Number of Antennas and Coded in Single Antenna

Table 4. 4 the comparison of coded data in single antenna and uncoded data in number of antenna

Input data = 100 bits in BPSK modulation				
Eb/No	Coded data N=1 BER	Uncoded data N=1 BER	Uncoded data N=32 BER	Uncoded data N=128 BER
-1	0.2	0.1	0.0032	0.00081
1	0.021	0.056	0.0017	0.00043
4	$4.5*10^{-6}$	0.0125	0.00039	$9.7*10^{-5}$

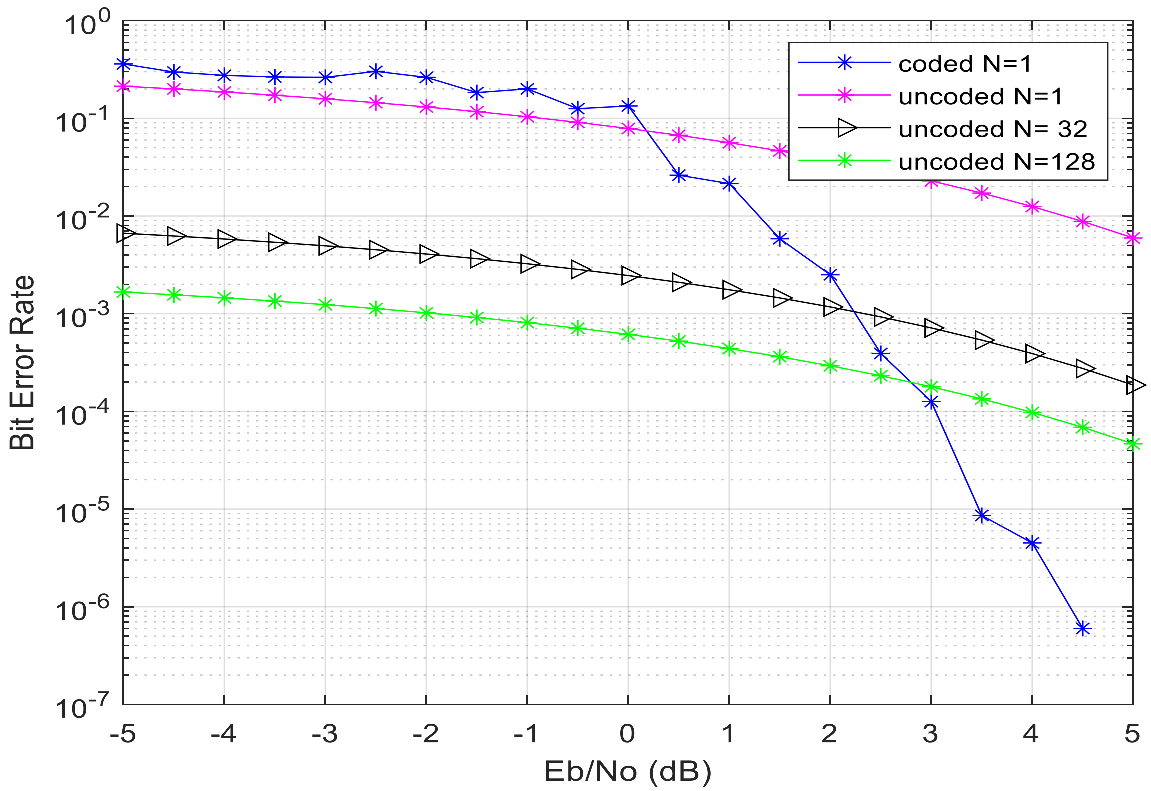


Figure 4. 7 The comparison of coded and uncoded data in different number of antenna

The simulation result shows a bit error rate in terms of Eb/No (dB) for coded data and uncoded data in a fixed number of transmitter antenna when the values of information bit =100 and code rate=1/3. The result is taken from -5 to 5 the number of Eb/No (dB) with increment 1 and by using BPSK modulation. As the figure shows, at very low EbNodB, the performance of uncoded data has low bit error rate than coded one. However, as the EbNodB increases, the bit error rate of coded data decreases exponentially while uncoded data shows only a slight change. Channel coding has a minimum value of BER than the transmitter has the number of antennas. We consider from the simulation result, the values of Eb/No (dB) from -5 to 0 the bit error rate of uncoded data is lower after Eb/No (dB) =1 coded data fast exponentially decreases the bit error rate.

4.6. Coded and Uncoded with Perfect and Imperfect CSI

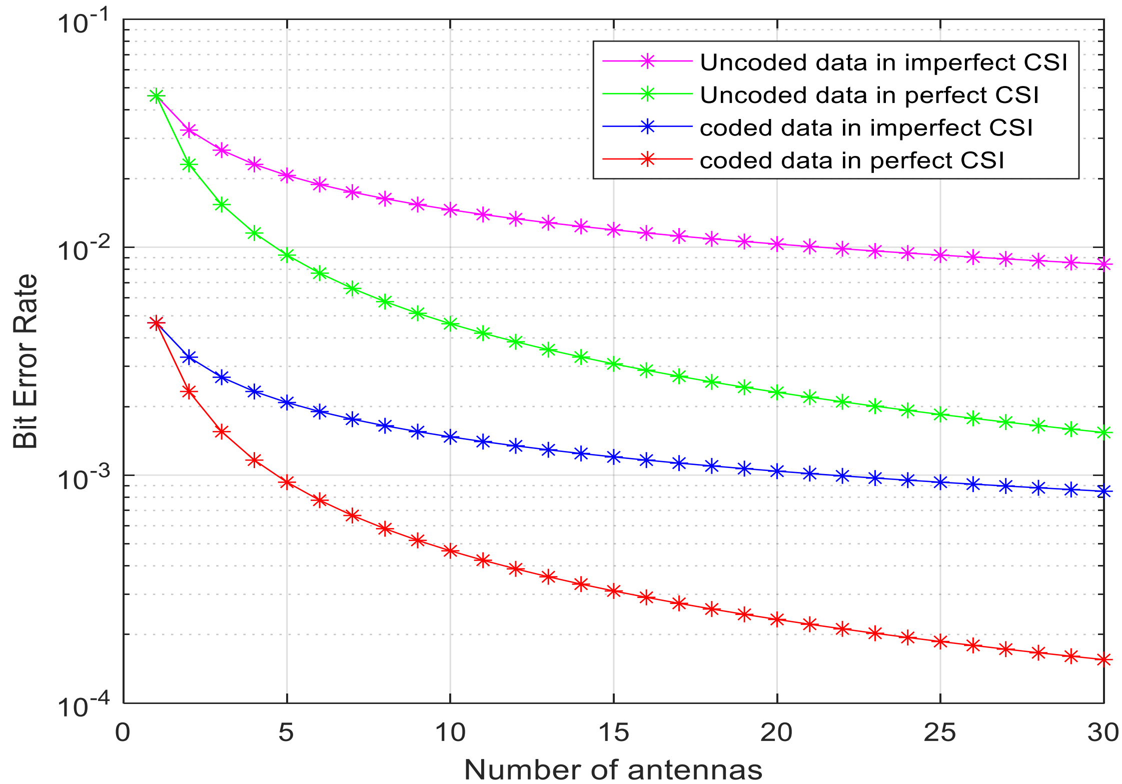


Figure 4. 8 Number of antenna Vs bit error rate for coded and uncoded data

Table 4. 5 Comparison of uncoded and coded data in number of antennas

Input data = 1024 bits in BPSK modulation and EbNodB = 1.5				
Number of antennas	Uncoded data in imperfect CSI BER	Uncoded data in perfect CSI BER	coded data in imperfect CSI BER	coded data in perfect CSI BER
1	0.044	0.044	0.0056	0.0056
10	0.014	0.0044	0.0017	0.00056
30	0.008	0.0014	0.0010	0.00018

Figure 4.8 and Table 4.5 is the simulation result of the compassion between uncoded and coded data by using perfect and imperfect CSI in terms of the bit error rate versus numbers of

transmitting antennas. As the number of a base station antenna increase, the probability of error or bit error rate will be decreased. As shown in the figure, when the number transmitter antenna N=1 the bit error rate of encoded data = 0.044 and coded data =0.0056 using EbNodB =1.5 the difference is 0.0384. From the result, both uncoded and coded data decrease the bit error rate at the same time when the number of antennas increases. But massive MIMO with channel coding has a lower bit error rate than without channel coding. And the perfect channel has better performance than an imperfect channel.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Massive-MIMO systems provide high reliability to the user terminal by deploying a huge number of antennas. We could see that as the energy per bit to noise power spectral density ratio rises, the bit error rate decreases, and that BPSK modulation has better values than other higher-order modulations. There are two advanced channel coding schemes for future wireless communication LDPC and polar code. LDPC is outperformed than polar code with successive cancellation and with successive cancellation List. When increasing the redundancy bits into the information bit the probability of error or bit error rate will decrease.

The performance of the base station changes significantly when more antennas are used, which explains why Massive-MIMO systems are used in wireless communications. In other words, increase the reliability of data transmission. A large number of antennas perform better than a smaller number of antennas. And the base station when using perfect CSI has high reliability because the transmitter is known to channel properties of a communication link. This data illustrates how a signal travels from the transmitter to the receiver and represents the cumulative effects of scattering, fading, and power loss as a function of distance. Channel coding is exponentially decreased the bit error rate of the system and the number of antennas decreases slightly. The result of the simulation shows the bit error rate of massive MIMO with channel coding lower than without channel coding system.

5.2. Recommendation

Channel coding in massive MIMO system doing in this thesis considers the bit error rate (reliability). Further works can be done because channel coding has many advantages such as increase spectral efficiency, capacity, and throughput of massive MIMO. This thesis works only on the reliability of massive MIMO in downlink transmission. We recommend that the next work have to include spectral efficiency, capacity, and throughput.

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APPENDIX

```
Clc
Clear all
Close all
EbNodB = 1.5;
MaxItrs = 20;
rmax = 3;
maxqr = 31;
maxqL = 127;
offset = 2;
load base_matrices/NR_2_6_52.txt
B = NR_2_6_52;
[mb,nb] = size(B);
z = 52;
Slen = sum(B(:)~=-1); %number of non -1 in B
Slenmax = max(sum(B ~= -1,2));

kb = nb - mb;
k = kb * z; %number of message bits
Rate = 1/2;
nbRM = ceil(kb/Rate) + 2;
n = nbRM * z;
mbRM = nbRM - kb;

EbNo = 10^(EbNodB/10);
sigma = sqrt(1/(2*(k/(n-2*z))*EbNo));

Nbiterrs = 0; Nblkerrs = 0; Nblocks = 1000;
parfor i = 1: Nblocks
    msg = randi([0 1],1,k);
    cword = nrldpc_encode(B,z,msg);
```

```
cword = cword(1:n);
s = 1 - 2 * cword; %BPSK bit to symbol conversion
r = s + sigma * randn(1,n); %AWGN channel I
r(1:2*z) = 0;
rq = floor(r/rmax*maxqr);
rq(rq>maxqr) = maxqr;
rq(rq<-(maxqr+1)) = -(maxqr+1);

% iterative message-passing layered decoding
L = rq;
itr = 0; %iteration number
R = zeros(Slen,z);
treg = zeros(Slenmax,z);
while itr < MaxItrs
    Ri = 0;
    for lyr = 1:mbRM
        ti = 0; %number of non -1 in row=lyr
        for col = find(B(lyr,1:nbRM) ~= -1)
            ti = ti + 1;
            Ri = Ri + 1;
            %Subtraction
            L((col-1)*z+1:col*z) = L((col-1)*z+1:col*z)-R(Ri,:);
            %Row alignment and store in treg
            temp = mul_sh(L((col-1)*z+1:col*z),B(lyr,col));
            temp(temp>maxqr) = maxqr;
            temp(temp<-(maxqr+1)) = -(maxqr+1);
            treg(ti,:) = temp;
        end
        %minsum on treg: ti x z
        for i1 = 1:z %treg(1:ti,i1)
            [min1,pos] = min(abs(treg(1:ti,i1)));
```

```
min2 =   min(abs(treg([1:pos-1 pos+1:ti],i1)));
        S = 2*(treg(1:ti,i1)>=0)-1;
        parity = prod(S);
        %offset
        min1 = min1 - offset;
        if min1<0
            min1 = 0;
        end
        min2 = min2 - offset;
        if min2<0
            min2 = 0;
        end
        treg(1:ti,i1) = min1;
        treg(pos,i1) = min2;
        treg(1:ti,i1) = parity*S.*treg(1:ti,i1); %assign signs
    end

    Ri = Ri - ti; %reset the storage counter
    ti = 0;
    for col = find(B(lyr,1:nbRM) ~= -1)
            Ri = Ri + 1;
            ti = ti + 1;
            %Column alignment
            R(Ri,:) = mul_sh(treg(ti,:),z-B(lyr,col));
            %Addition
            temp = L((col-1)*z+1:col*z)+R(Ri,:);
            temp(temp>maxqL) = maxqL;
            temp(temp<-(maxqL+1)) = -(maxqL+1);
            L((col-1)*z+1:col*z) = temp;
    end
end
```

```
        msg_cap = L(1:k) < 0; %decision
        itr = itr + 1;
    end
            Nerrs = sum(msg ~= msg_cap);
    if Nerrs > 0
        Nbiterrs = Nbiterrs + Nerrs;
        Nblkerrs = Nblkerrs + 1;
    end
end
M=1:1:30;
BER_sim = (Nbiterrs/k/Nblocks)./M;
BER_sim1 = (Nbiterrs/k/Nblocks)./sqrt(M);
EbNodB = 1.5;
R1 = 1;
EbNo1 = 10.^(EbNodB/10);
sigma1 = sqrt(1./(2*R1*EbNo));
N1 = 520;
Nerr1 = 0;  Nblocks1 = 1000;
for i = 1: Nblocks1
    msg1 = randi([0 1],1,N1);
    s1 = 1-2 *msg1;
 r1 = s1 + sigma1*randn(1,N1);

   msg_cap1=(r1<0);
  Nerrs1 = Nerr1 + sum(msg1~=msg_cap1);

end
BER_sim2 = (Nerrs1/N1)./ M;
BER_sim11 = (Nerrs1/N1)./sqrt(M );

semilogy(M,BER_sim11,'m-*');
```

```
hold on
semilogy(M,BER_sim2,'g-*');
hold on
semilogy(M,BER_sim1,'b-*');
hold on
semilogy(M,BER_sim,'r-*');
hold on
grid on
xlabel('Number of antennas')
ylabel('Bit Error Rate')
hold on
legend('Uncoded data in imperfect CSI','Uncoded data in perfect CSI','coded data in imperfect
CSI','coded data in perfect CSI');
 /////////////////////////////////////////////////////////////////
function cword = nrldpc_encode(B,z,msg)
[m,n] = size(B);
cword = zeros(1,n*z);
cword(1:(n-m)*z) = msg;
 temp = zeros(1,z);
for i = 1:4 %row 1 to 4
    for j = 1:n-m %message columns
        temp = mod(temp + mul_sh(msg((j-1)*z+1:j*z),B(i,j)),2);
    end
end
if B(2,n-m+1) == -1
    p1_sh = B(3,n-m+1);
else
    p1_sh = B(2,n-m+1);
end
cword((n-m)*z+1:(n-m+1)*z) = mul_sh(temp,z-p1_sh); %p1
%Find p2, p3, p4
```

```
for i = 1:3
    temp = zeros(1,z);
    for j = 1:n-m+i
        temp = mod(temp + mul_sh(cword((j-1)*z+1:j*z),B(i,j)),2);
    end
    cword((n-m+i)*z+1:(n-m+i+1)*z) = temp;
end
%Remaining parities
for i = 5:m
    temp = zeros(1,z);
    for j = 1:n-m+4
        temp = mod(temp + mul_sh(cword((j-1)*z+1:j*z),B(i,j)),2);
    end
    cword((n-m+i-1)*z+1:(n-m+i)*z) = temp;
end
/////////////////////////////////////////////////////////////////////
 function out = check_cword(B,z,c)
[m,n] = size(B);

syn = zeros(m*z,1); %Hc^T
for i = 1:m
    for j = 1:n
        syn((i-1)*z+1:i*z) = mod(syn((i-1)*z+1:i*z) + mul_sh(c((j-1)*z+1:j*z),B(i,j))',2);
    end
end
if any(syn)
    out = 0;
else
out = 1;
end
```