[B.Sc. Engg. Thesis]

A Comparative Performance Analysis of LDPC coded SCMA with Different types of Multiple Access Schemes

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To
Our Beloved Parents

Declaration by Author

We hereby certify that we have developed this thesis titled "**A Comparative Performance Analysis of LDPC Coded SCMA with Different types of Multiple Access Schemes**" entirely based on our efforts under the sincere guidance of our supervisor Dr. Mohammad Ismat Kadir. All of the sources used in this thesis have been cited properly. No portion of the work presented in this thesis has been submitted in support of any application for any other degree of qualification to this or any other university or institute of learning.

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All praise are to the almighty for giving us the chance to work on this thesis and enabling us to give the effort to make some contribution. All the opportunities granted by the creator led us to this day working on a mass problem and trying to help.

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ABSTRACT

For future generation wireless communication sparse code multiple access (SCMA) is a promising technique because it is an effective non-orthogonal multiple access (NOMA) technique. Because of its sparsity, SCMA has a higher overloading tolerance and lower complexity when compared to orthogonal techniques. In this paper, we propose a LDPC coded SCMA scheme in which LDPC encoding and decoding algorithm is used. As orthogonal frequency division multiplexing (OFDM) and orthogonal frequency division multiple access (OFDMA) have several drawbacks such as high peak to average power ratio (PAPR), symbol and frequency synchronization problems, inter symbol interference (ISI) and inter carrier interference (ICI), these schemes are replaced by code domain multiple access (CDMA). CDMA is a multiplexing technique in which multiple users simultaneously and asynchronously access a channel by modulating and spreading their information-bearing signals with pre-assigned signature sequences. CDMA systems provide an enhanced bit error rate (BER) performance but the performance and capacity of CDMA systems are diminished by self-interference (SI) and multi-user interference (MUI) caused by multi path interference (MPI) and multiple access interference (MAI). SCMA is an evolved variant of CDMA in which multiple users are separated by assigning distinctive codebook and allows overloading a huge number of users in order to increase overall rate and massive connectivity. In this work, we present a uplink SCMA system with LDPC channel coding which allows an efficient multiuser detection and exploits the sparsity of codebook to achieve lower BER performance. According to the simulation results, the proposed LDPC coded SCMA scheme has a 3dB Bit Error Rate (BER) performance gain over traditional multiple access schemes. Thus for next generation communication systems our proposed scheme will be an effective scheme.

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Chapter 1

Introduction

Multiple access protocols allow for simultaneous usage of the wireless network by multiple users. This is typically accomplished by allotting a portion of the available bandwidth to each user to reduce interference problems between two portions and maximize the usage of the entire spectrum.

1.1 Wireless Communication

The medium used for communication can be guided or unguided, and communication systems can be wired or wireless. A physical channel, such as coaxial cables, twisted pair cables, optical fiber links, etc., serves as the medium in wired communication and directs the signal as it travels from one point to another [1]. There is no substitute for digital wireless communication in the era of modern science. Furthermore, fast data transmission rates, great spectral efficiency, extremely low latency, ultra-reliable audio, and video transmission, flexible synchronization, low power consumption, and other characteristics are essential for digital wireless communications [2]. A simplified block diagram of a communication system is shown in fig 1.1.

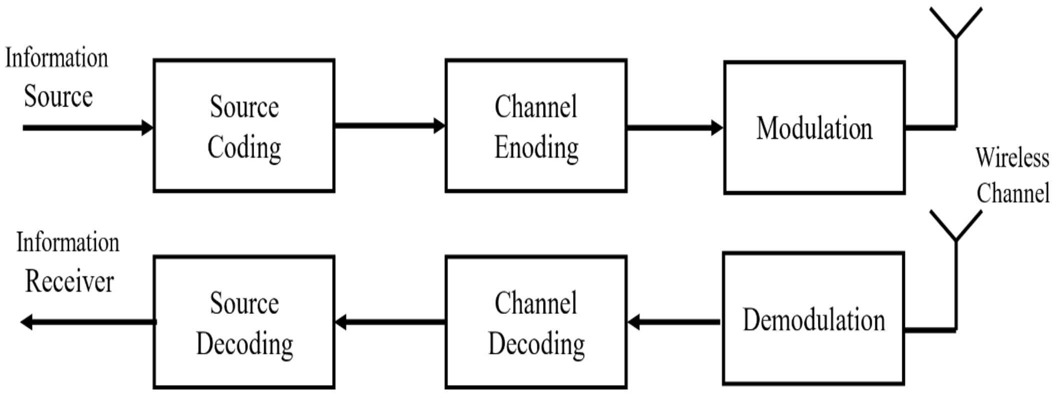

Figure 1. 1 Block Diagram Of Wireless Communication Systems [3]

Although wireless communication has many advantages, it also has some disadvantages such as low speed, jamming, being less secure, easily hacked, open to interference [4]. The primary goal of wireless communication is to send data, including audio, video, text, and other types of data, without any interference or lag time. Other requirements for wireless communication systems include enhanced synchronization, reduced battery consumption, and security protection. Some modulation approaches could be able to meet these needs. But in the current contemporary era, wireless communication users are expanding quickly, and this upward tendency will persist for the ensuing decades. In light of this enormous demand, a few complex technologies that are currently in use and will be crucial to the development of future wireless systems are identified and briefly described.

1.2 Why Do We Need Multiple Access Scheme In Wireless Communication?

If there is only one user, we don't need multiple access techniques for wireless communication. However, if more than one user needs to share a wireless communication system, we must have a method that enables several users to access the same base station, as the term implies.

In order to share radio spectrum among two or more mobile users, multiple access approach is utilized. It is frequently important to allow users to send and receive data simultaneously in wireless communication. Numerous mobile users can share a limited quantity of radio airwaves simultaneously thanks to multiple access mechanisms. To reach high capacity, several users must be given access to the available bandwidth (or number of channels) at once, which necessitates spectrum sharing. This must be done with minimal system performance reduction to ensure high-quality communications.

1.3 Multiple Access Schemes

In telecommunications networks, multiple access refers to methods that let several users effectively share constrained network resources [5]. It is necessary to implement an MA scheme to manage the distribution of bandwidth among multiple users when multiple users are attempting to access such constrained bandwidth to ensure that all users can utilize the network's services and that no single user uses up all of its resources [6]. A systemic order of multiple access schemes is shown in fid 1.2.

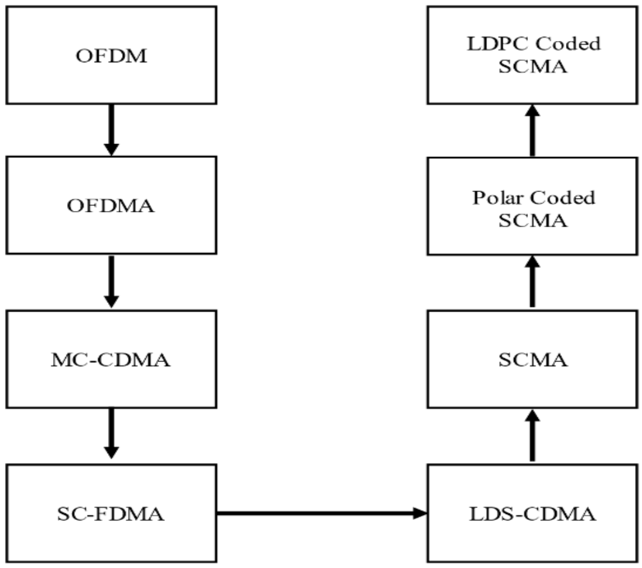

Figure 1. 2: Systemic Order of Multiple Access Schemes

Researchers have been searching for the finest MA scheme to adhere to the above straightforward concept of resource sharing among several users since the very beginning of contemporary communications.

As the starting point of MA generation, very obvious and basic methods of combining bandwidth, frequency, and time separation were chosen. Frequency modulation (FM) allowed the earliest MA communications systems to divide the available frequency spectrum for a specific system into several frequency channels, each of which was allocated to a single user and occupied a portion of the total available bandwidth [7]. Without experiencing much interference from other users utilizing the system concurrently, several users might access it using different frequency channels [8].

High spectrum efficiency and increased robustness against frequency-selective fading or narrowband interference are two of the key benefits of using OFDM [9]. To send and receive information simultaneously, two or more mobile users can share radio bandwidth using the multiple access technique. Scalability, uplink orthogonality, MIMO friendliness, and the capacity to benefit from channel frequency selectivity are among the key benefits of OFDMA [10]. The three main multiple access methods that are utilized to divide the available bandwidth in a wireless communication system are FDMA, TDMA, and CDMA [11].

Although spread spectrum or MC-CDMA is a type of CDMA, we apply the spreading in the frequency domain (rather than in the time domain as in Direct Sequence CDMA) [12]. Due to its low Peak to Average Power Ratio (PAPR) characteristic when compared to rival Orthogonal FDMA (OFDMA) approaches, SINGLE Carrier (SC) Frequency Division Multiple Access (FDMA) techniques for uplink transmission have attracted considerable interest [13-15].

One of the Non-Orthogonal Multiple Access (NOMA) possibilities for 5G, the fifth-generation mobile network, is Sparse Code Multiple Access (SCMA). Each frequency layer transmits many overlapping SCMA code blocks, forcing the receiver to cancel any undesired SCMA code blocks [16]. Polar coded sparse code multiple access (SCMA) systems is a simple but new iterative multiuser detection framework proposed, which consists of a message passing algorithm (MPA) based multiuser detector and a soft-input soft-output (SISO) successive cancellation (SC) polar decoder [9]. A strong contender for the multiple access scheme in the 5G communication system is the polar-coded SCMA system with a JIDD receiver [17]. The LDPC-coded SCMA receiver is a great alternative for next-generation wireless communications [18]. When compared to a typical SCMA receiver, the LDPC coded SCMA method can offer significant performance gains and a narrower waterfall zone in terms of BER for both AWGN channels and Rayleigh fading channels [19].

1.4 Motivation

Faster access, greater transmission rates, support for higher user densities, and an improved user experience are all goals of the 5G air interface. One of the fundamental physical layer technologies used in wireless communications is multiple access, which enables wireless base stations to identify and service numerous different terminal users at once. Modern systems frequently employ the orthogonal multiple access technique, which ensures that users are orthogonal to one another in at least one radio resource dimension (for example, frequency, time, code. etc.). In preparation for possible use with 5G and other advanced communications networks, SCMA is a non-orthogonal multiple-access technology. The goal is to improve wireless radio access's spectrum efficiency via SCMA, or Sparse Code Multiple Access. Multiple users will transmit using various codebooks on the same resource blocks in SCMA. Sparse codebooks reduce user collision, making SCMA resistant to intervention from other users. The capacity, low latency access need, and vast connectivity of 5G cannot be met by orthogonal multiple access technology since access to resources is proportional to the number of users. Therefore, research into 5G Multiple Access will concentrate on non-orthogonal multiple access. In 5G communications, if non-orthogonal multiple access is used, SCMA is designed to fulfil the required demand of services.

1.5 Contribution

Our proposed scheme's contributions are as follows:

- We have designed LDPC coded SCMA scheme on the rayliegh fading channel. As SCMA is the key enabling NOMA techniques in fifth generation communication, provides an enhanced bit error rate performance due to its sparsity of codebook. Low density parity check code is capacity approaching error correcting code which provides channel capacity near to Shannon’s limit performance, high throughput, low latency low decoding complexity and rate complexity. Hence, we have synthesized the LDPC encoding and decoding process as a channel coding with SCMA system.

- The performance analysis of this proposed scheme has been done comparison with SCMA, polar-coded SCMA for a wireless communication system.

- We have also compared the performance of the proposed scheme with different multiple access techniques such as OFDM, OFDMA, and MC-CDMA for better evolution.

1.6 Outcome

The key outcome of this thesis is to effectively improve transmission technique performance for 5G and future wireless networks and efficiently fulfil the demands of services required. Previously, numerous access techniques were employed by 5G communication systems. In this instance, Low-Density Parity Check Code (LDPC) based transmission using an rayliegh fading channel has been proposed to enhance the performance of 5G and next-generation wireless networks. When compared to conventional alternative multiple access techniques, LDPC-coded SCMA performs better because the bit error rate (BER) is much lower, channel capacity is greater, less complexity in decoding process. Thus LDPC coded SCMA scheme can provides higher rate data transmission with lower error rate for fifth generation and future wireless communication systems.

1.7 Summary

It has become essential to improve wireless communication performance for 5G and future wireless systems. Wireless communication users are growing every day, so the system needs to be capable of handling the rising demands. To meet this enormous demand, it is essential to boost bandwidth, synchronization capabilities, and error performance. To meet the above requirements, sparse code multiple access (SCMA) based on low-density parity-check code (LDPC) has been investigated. Here, It is shown that LDPC coded SCMA scheme is a more effective scheme than others and also it has better performance than other multiple access schemes.

1.8 Thesis Organization

The thesis is structured as follows:

In **Chapter 1**, various types of wireless communication technologies are discussed, along with a brief overview of the various multiple access techniques used in wireless communication systems. This chapter also covers the motivation for this work, the contributions to this thesis, and the expected outcomes.

Chapter 2 covers the literature review. It also lists the authors' names, the study goal, the algorithms employed, the distinctiveness of the researches, and the outcomes.

Chapter 3 describes single carrier modulation with its advantages and disadvantages. Also describes different types of communication systems based on antenna types, multicarrier modulation with different types of multiple access schemes such as OFDM, OFDMA, and MC-CDMA in details.

Chapter 4 is the main body of this thesis because it describes sparse code multiple access (SCMA) scheme in detail along with codebook generation, encoding and multiplexing process, decoding process. A quick survey on Polar coded SCMA and the system model of LDPC coded SCMA system, MAP based SCMA detection along with LDPC decoding and the synthesis SCMA detection and LDPC decoding in this study.

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Chapter 5 discusses all of the assessments as well as the outcomes analysis. It compares the performance of LDPC coded SCMA with conventional SCMA, polar coded SCMA and other multiple access schemes such as OFDM, OFDMA and MC-CDMA system.

Chapter 6 describes the conclusion of this thesis and future work.

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Chapter 2

Literature Review

It is frequently preferred in wireless communication systems for the subscriber to be able to simultaneously submit information from the mobile station to the base station and receive information from the base station to the mobile station.

A cellular system divides any given territory into cells, each with its own mobile unit that communicates with a base station. The basic purpose of cellular system design is to increase channel capacity, or to accommodate as many calls as possible in a given bandwidth while maintaining adequate service quality.

We would like to summarize the significant contributions of the relevant works that influenced the development of the different multiple access techniques.

Here we have dealt with some of the multiple access techniques in communication systems such as OFDM, OFDMA, SC-FDMA, MC-CDMA, SCMA, polar-coded SCMA, and LDPC-coded SCMA. We analysed their performance by plotting the graph of BER vs SNR. In today's era of 5G and 6G communication systems, a High data rate is very important.

Paper Title: Orthogonal Frequency Division Multiplexing: A Multi-Carrier Modulation Scheme

Authors: Yiyan Wu, William Y. Zou

Orthogonal frequency division multiplexing (OFDM) is a multi-carrier modulation technique that was first introduced more than three decades ago. Advancements in digital signal processing (DSP) and very large scale integrated circuit (VLSI) technologies had passed the way for widespread application of OFDM techniques in consumer electronics. OFDM has been evaluated for terrestrial digital television broadcasting in Europe and elsewhere. The successful implementation of OFDM is in digital audio broadcasting (DAB), satellite broadcasting, asymmetric digital subscriber line (ADSL) technology. This paper represents the OFDM system in details and the review of the techniques, implementations, developments and its advantages and disadvantages in comparison with other techniques. This paper showed that OFDM, as a parallel transmission technique, was less sensitive to changes in sampling time than serial transmission techniques. In comparison to equalizers in a single carrier system, the complexity of an FFT-based OFDM system grows logarithmically with the increase of channel multipath spread for a fixed bandwidth efficiency. For wideband mobile communication a proper coded and interleaved OFDM system had better performance. But in comparison with single carrier system, high peak to average power ratio (PAPR) was the main disadvantage of OFDM system [1].

Paper Title: Performance Analysis of Channel Estimation in OFDM Systems

Authors: Jihyung Kim, Jeongho Park, Daesik Hong

Orthogonal frequency division multiplexing (OFDM) has been the subject of numerous studies in wireless communications due to its high transmission capability and resistance to multipath delay. As radio channels are frequency-selective and time-varying in wideband mobile communication systems, dynamic estimation is required. In coherent OFDM, channel estimation is typically performed by inserting known subcarriers into the time-frequency grid using pilot tones. This paper presented an analysis of channel estimation using an interpolation technique in OFDM systems and derived a criterion for .the adaptive interval of pilot subcarriers. The final result of their research was that the length of channel delay and the interval of pilot subcarriers dominated the mean-square error (mse) of comb-type estimators which was dependent on the frequency selectivity of the channel. For indoor channels, the mse performance of comb-type estimators with an adequate interval of pilot subcarriers outperformed that of block-type estimators [2].

Paper Title: Performance Analysis of Equalized OFDM Systems in Rayleigh Fading

Authors: Ming-Xian Chang, and Yu T. Su.

OFDM is a promising candidate technique for high-speed transmissions in a frequency-selective fading environment. By converting a wideband signal into a parallel array of properly spaced narrowband signals, each narrowband OFDM signal suffers from frequency-flat fading and thus requires only a one-tap equalizer to compensate for the corresponding multiplicative channel distortion. In most cases, channel estimation is required to compensate for the amplitude and phase distortions associated with a received OFDM waveform. This paper described a systematic approach for analyzing the bit-error probability (BEP) of equalized OFDM signals in Rayleigh fading. The BEP expression is function of the average bit signal energy to noise ratio (SNR) expressed as $\overline{\gamma_b} \triangleq \overline{E_b}/N_0$, and some correlation coefficients that depend on the true channel statistic and a linear pilot assisted channel estimation is used. Their analysis can be used to estimate the BEP behavior of different signal constellations such as QAM, PSK (BPSK, QPSK), and DPSK as long as the fading process is modeled as a band-pass stationary zero-mean complex Gaussian process. Their system performance was good but fast fading channel caused inter-channel interference (ICI) amongst sub-channels [3] .

Paper Title: Pilot Structures for the Uplink Single Carrier FDMA Transmission Systems

Authors: Byung Jang Jeong and Hyun Kyu Chung

In this study, a straightforward time domain multiplexing (TDM) pilot structure is suggested for uplink SC-FDMA communications. The suggested pilot structure may provide complete frequency resolution in the frequency domain even though it is communicated via a condensed block in the time domains. Simulations have demonstrated that the proposed pilot structure performs better than the staggered pilot structure. The proposed method’s performance enhancement comes at the expense of a minor rise in computational complexity.

Consider the fact that the distributed SC-FDMA with even-numbered repetition factor makes it challenging to implement the proposed pilot structure. In such situation, just one of the two short blocks is always used to broadcast pilot symbols for a single user, making it challenging to account for variations in the temporal channel [4].

Paper Title: Performance Evaluation of SC-FDMA Systems Using Wireless Images

Authors: Farouk Al-Fahaidy, Khaled Abdullah Al Soufy, F. S. Al-kamali

Due to its low peak-to-average power ratio and low susceptibility to carrier frequency offset, a single carrier frequency division multiple access (SC-FDMA) has recently attracted a lot of interest in wireless communications. The goal of this study is to investigate and evaluate SC-FDMA wireless picture transmission while taking into account various basis functions, modulation schemes, and subcarrier mapping systems. It is demonstrated through a number of tests that wireless picture transmission over SC-FDMA systems is effectively possible. Additionally, simulation results demonstrated that, regardless of the wireless channel or the chosen modulation scheme, interleaved systems perform better than localized systems and significantly improve the clarity of the received image. Additionally, according to the results, the discrete cosine transform (DCT)-based SC-FDMA (DCT-SC-FDMA) and discrete sine transform (DST-SC-FDMA)-based SC-FDMA (DST-SC-FDMA) systems perform better than the traditional discrete Fourier transform (DFT)-based SC-FDMA (DFT-SC-FDMA) system in terms of Mean Square Error (MSE) and Peak Signal-to-Noise Ratio (PSNR) values [5].

Paper Title: Performance Analysis of OFDMA and SC-FDMA

Authors: M. Al-Rawi

The main goal of high-speed digital communication systems is how to maximize the data rate while minimizing the bit error rate. In this paper, four strategies are discussed in detail to achieve this point.

Orthogonal frequency division multiplexing (OFDM), single carrier frequency division equalization (SC-FDE), orthogonal frequency division multiple access(OFDMA), and single carrier frequency division multiple access(SC-FDMA) are briefly explained here to attain better performance. The performance analysis of OFDMA and SC-FDMA is calculated over a multipath channel with AWGN, in connection with bit error rate (BER) versus signal-to-noise ratio (SNR).

Here, the performance analysis measures over MMSE equalizer. Multiple mapping strategies were used in this paper named localized mapping and interleaved mapping. It was noticed that the performance of OFDMA is not better than SC-FDMA for both mapping strategies with QPSK modulation format. But the performance of OFDMA is a little bit better than that of SC-FDMA for both mapping strategies with 16QAM modulation format [6].

Paper Title: Improved Performance of a Random OFDMA Mobile Communication System

Authors: R. Nogueroles, M. Bossert, **A.** Donder, and **V.** Zyablov

The uplink performance of an OFDMA is examined in this research (Orthogonal Frequency Division Multiple Access) in the use of mobile communications. They begin by describing the MC-FDMA-based random OFDMA system, in which each user has a set of the randomly chosen sub-channel. They also offer various system implementations based on the assumed amount of block synchronization and outline the performance criteria taken into account for this system's evaluation.

Depending on the level of block synchronization, they have offered three different random OFDMA system implementations. They have displayed the simulation results for the various system implementations, and they have outlined the performance criteria taken into account for the system evaluation.

They have discussed many ways to enhance system performance by implementing better receivers capable of SIC or capture, which will result in a significant performance boost as demonstrated by some simulation results.

Furthermore, they have demonstrated how the traffic load affects system performance and how they can enhance it by utilizing various sub-channel sets according to the traffic volume of the system. They have demonstrated how very high user transmission rates (greater than 2 Mb/s) may be achieved with the right parameters, making this system appropriate for multimedia applications [7].

Paper Title: Performance Analysis of OFDMA in LTE

Authors: S.S. Prasad, C.K. Shukla, Raad Farhood Chisab

Mobile communications has evolved into a commonplace commodity. It has progressed from an expensive technology for a few select individuals to today's ubiquitous systems used by the vast majority of the world's population over the last few decades. Third Generation (3G) system started operations during October, 2002 in Japan and The Long-Term Evolution (L TE) is often called "4G". The LTE is based on the principle of multiple accesses, which is a radio transmission scheme that allows multiple users to transmit signals at the same time without interfering with each other. The LTE mobile system employs OFDMA in the downlink to improve spectrum efficiency, enable flexible users resource allocation, and transmit data from the base station to mobile users while in the uplink, the data is transmitted from the mobile user to the base station using Single Carrier Frequency Division Multiple Access (SC-FDMA). In this paper the properties of orthogonal frequency division multiplexing is introduced and discussed about the strengths and weaknesses of OFDMA system, and highlights the factor that enhances its performance in LTE. OFDMA system can efficiently overcome the problems of inter symbol interference (ISI) and inter carrier interference (ICI) but the composite time-domain signal begins to resemble Gaussian noise with a high Peak-to-Average Power Ratio as the number of subcarriers increases. Multiple User Signals are mixed in both frequency and time domains, which causes synchronization errors. The final results of this research showed that the performance of OFDMA in LTE depends on several modulation techniques such as BPSK (Binary Phase Shift Keying), QPSK (Quadrature Phase Shift Keying) and in higher order modulation due to high PAPR, error probability, SNR, BER increases which causes a serious problems in communication systems [8].

Paper Title: Simulation Based Performance Analysis of MC-CDMA and CDMA over Rayleigh Fading Channel

Authors: Mohammed Faisal, Jia Uddin, Iqbal Hasan Haider

Conventional code division multiplexing (CDM) is incapable of combating multipath propagation effects due to a randomly generated pseudo noise sequence is multiplied with the original signal and spreads in frequency domain. CDMA technology suffer from frequency selective fading badly particularly in the downlink which causes interference in the transmitted signal. To overcome this problem, the combination of OFDM and CDMA develop a new system named multi carrier code division multiple access (MC-CDMA). This paper represents the performance comparison of CDMA and MC-CDMA over Rayleigh fading channel by analysing the BER with respect to SNR.

In CDMA system all data symbols share the same subcarriers, and their signals arrive at the receiver end remain unchanged due to the use of orthogonal spreading codes and the frequency diversity caused by multipath propagation is exploited for expected BER performance over OFDM. The final result of this analysis is that the MC-CDMA outperformed better even for an increased number of subscribers than CDMA over Rayleigh fading channel [9].

Paper Title: Performance Analysis of DS-CDMA and MC-CDMA Systems

Authors: Yoonill Lee

In recent years, the demand for high rate data transmission has rapidly increased because users want to stream more multimedia, such as video, faster over the Internet. Inter symbol interference (ISI) occurs when the transmitted data symbol duration becomes less than the delay spread caused by the multi-path channel. To over this problem spread spectrum is introduced and applied in multiple access techniques to share a communication channel with a number of users at the same time. Direct sequence code division multiple access is an application of spread spectrum in which spreading sequence are orthogonal to each other. In this paper, a performance analysis of DS-CDMA and MC-CDMA is evaluated. Data is spread using a time-domain spreading sequence in DS-CDMA, on the other hand, MC-CDMA spreads data across multiple subcarriers using a frequency-domain spreading sequence. The simulation result shows better performance for maximal ratio combining (MRC) and equal gain combining (EGC) in MC-CDMA than DS-CDMA. When number of users are less MRC shows better performance than EGC as the MRC does not increase multiple access interference (MAI) but when the number of users are greater then, EGC shows better performance because MRC increases MAI [10].

Paper Title: Performance Evaluation of MC-CDMA Systems with Single User Detection Technique using Kernel and Linear Adaptive Method

Authors: Rachid Fateh, Anouar Darif, Safi Said

The multi-carrier code division multiple access (MC-CDMA) systems is by far the most intensively researched of all the methods combining multi-carrier modulation and spread spectrum. The performance of the MC-CDMA system concerning important single-user detection methods is presented in this research. They are particularly interested in issues relating to the identification and equalization of mobile radio channels utilizing a reproducing kernel and a linear adaptive algorithm in Hilbert space for MC-CDMA systems. They evaluated the effectiveness of these algorithms in this context using real-world frequency selective fading channels, or BRANs, which are standardized for MC-CDMA systems. After channel identification, the equalization issue is addressed using the orthogonality restoration combination (ORC) and minimal mean square error (MMSE) equalizer procedures to fix the channel distortion. Results from simulations show that the kernel algorithm is effective for real-world channels [11].

Paper Title: BER Analysis of SCMA Systems with Codebooks Based on Star-QAM Signalling Constellations

Authors: Lisu Yu, Pingzhi Fan, Xianfu Lei, P. Takis Mathiopoulos

SCMA is a non-orthogonal multiple-access technique being developed for use with 5G and other developed communications systems. SCMA is intended to improve the spectral efficiency of wireless radio access. SCMA can be considered as a combination of code division multiple access (CDMA) and frequency division multiple access (FDMA). The codebooks are based on multidimensional constellations, and the shaping gain allows them to outperform traditional spread code-based schemes. In this paper, the performance of sparse code multiple access (SCMA) systems with codebooks based on star-QAM signalling constellations over additive white Gaussian noise (AWGN) channels is described.

Sparse code multiple access (SCMA) which combines the advantages of low receiver complexity and outperforms low density signatures (LDS). The message passing algorithm (MPA) is used at the receiver to eliminate inter-user interference based on the sparsity of the code-words in SCMA systems. The design of the codebook is especially important for achieving their objectives. The bit error rate (BER) performance of SCMA codebook based on star-QAM constellations is determined by the phase angle of the signal constellation while the signal amplitude is determined. The cumulative distribution function (CDF) of the phase angle,φ with Gaussian noise interference had been used to get the theoretical expression of BER. Numerical analysis and computer simulations had revealed that the analytical and simulation results were well matched, particularly in the high SNR region [12].

Paper Title: Feasibility Analysis of SCMA in Logging Cable Telemetry Systems with an Optimal 16-point Codebook

Authors: Qian Cui, Kai Shuang

The telemetry system is critical in the application of geophysical exploration technology. The ability of the downhole acquisition equipment to reliably and at a high rate transfer signals to the surface receiver for data processing will directly affect the overall efficiency and accuracy of the logging system. In this article, feasibility of SCMA on SISO systems such as LCTSs is analyzed and then designed an optimal (6, 16, 2, 4)-SCMA codebook. A Logging Cable Telemetry System is a Single Input Single Output (SISO) system that transmits Optical frequency Division Multiple Access (OFDMA) signals at a rate of about 1Mbits (7000m distance) with 4 bits per sub-carrier. SCMA transmits signals over non-zero tones of each code-word with varying powers, which is a benefit of the rotated lattice constellation, allowing MPA to operate efficiently to cancel inter-layer interferences. OFDMA is a familiar techniques for LCTS transmission that uses Phase Shift Keying (PSK) or Quadrature Amplitude Modulation (QAM). LDS, SCMA, and OFDMA BER performance were compared with the same sub-carrier number. With the same transmission rate SCMA outperforms LDS and OFDMA with 2dB and over 1dB differences on SNR [13].

Paper Title: SCMA for Downlink Multiple Access of 5G Wireless Networks

Authors: Hosein Nikopour, Eric Yi, Alireza Bayesteh, Kelvin Au, Mark Hawryluck, Hadi Baligh, and Jianglei Ma

Future generation of wireless systems are expected to provide improved service quality, higher throughput, and lower latency. Multi-user multiple input multiple output (MU-MIMO) is a well-known multiple access technique that allows multiple users in a downlink wireless network to share given time-frequency and power resources. Non-orthogonal code domain multiple-access is an open-loop scheme for coordinating multiple users over shared time-frequency resources where sparse code multiple access (SCMA) is a scheme based on a non-orthogonal codebook that has near optimal spectral efficiency. In this paper, a multi-user SCMA (MU-SCMA) is introduced to improve a downlink network throughput. As a closed-loop system, MU-MIMO faces some practical challenges such as channel aging and the high overhead required to feedback channel state information (CSI) from users to a serving transmit point (TP). MU-SCMA system is more resistant to channel variations and enable overcome CSI feedback problem totally. User paring, rate adjustment, power sharing algorithms are used for MU-SCMA detection. The simulation results of this paper evaluated that MU-SCMA has 24 Mbps throughput and 779.7 Kbps coverage as compared with OFDMA and SCMA schemes [14].

Paper Title: Joint Detection and Decoding of Polar-Coded SCMA Systems
Authors: Shusen Jing, Chao Yang, Junmei Yang, Xiaohu You, and Chuan Zhang

Polar codes are capacity-achieving channel codes for binary-input discrete memoryless channels that are simple and efficient. Due to its low encoding and decoding complexity, polar code has recently been adopted as a channel coding scheme for control channels in 5G communication systems. Polar codes have been adopted as channel coding for uplink and downlink control information for the enhanced mobile broadband (eMBB) communication service in the ongoing 5th generation wireless systems (5G) standardization process of the 3rd generation partnership project (3GPP). Sparse-code multiple-access (SCMA) improves capacity and data rate for multi-user applications. Unlike traditional orthogonal multiple access schemes like CDMA, this novel scheme can support a much higher number of simultaneous connections and has been proposed as a competitive option for 5G air interface technique. In this work the possible joint detection and decoding (JDD) of SCMA and polar code system was analyzed. JDD is carried out by combining two factor graphs into a larger one, likelihood messages which are allowed to transmit among all the nodes. This scheme improves convergence speed along with error performance [15].

Paper Title: Polar Codes for SCMA Systems

Authors: Moniroshariieh Vameghestahbanati, Ian Marsland, Ramy H. Gohary, and Halim Yanikomeroglu

The need to support a variety of users and applications is growing, which necessitates the development of new techniques that can handle their demands. A novel framework that can meet the abovementioned demand is provided by the recently established non-orthogonal multiple access (NOMA) waveform configuration sparse code multiple access (SCMA) technique.

Sparse multidimensional codewords from many users are superimposed over shared orthogonal resources in SCMA, where the user count often exceeds the resource count. Considering two key differences, SCMA essentially represents an instance of overloaded code division multiple access (CDMA): First, SCMA directly encodes the incoming binary data stream using multidimensional complex codewords that are selected from a codebook set that is unique for each user. In CDMA, the input data stream is translated to QAM symbols and then passed via a CDMA spreader. In order to reduce multiuser interference, SCMA restricts the spreading matrix to be sparse, meaning that only a small number of users overlap in each shared resource. CDMA does not place this constraint.

Through the use of channel coding, such as turbo and LDPC codes, SCMA systems' performance can be enhanced. Turbo-coded SCMA systems' bit error probability (BER) performance was examined in [16]. For SCMA systems, a turbo concept with an iterative multiuser receiver was put out in [17], and [18] examined an uplink LDPC-coded SCMA system.

Polar codes are a different class of channel codes that are based on channel polarization . When polarizing a channel, a collection of N polarized channels known as the bit channels are created from N independently occurring binary discrete memoryless channels. When compared to existing coding methods, polar codes bring a newly developed error-correcting code type that can eventually reach the capacity of discrete memoryless channels as the codeword length approaches infinity.

The performance of two polar-coded algorithms for uplink SCMA systems operating over fast and block fading channels have designed and compared in this research. The first method is referred to as bit-interleaved polar coded modulation (BIPCM), and the second method is referred to as multilevel polar coding (MLPC). Based on the nonbinary message passing algorithm (MPA) detection and both successive cancellation (SC) and successive cancellation list (SCL) decoding techniques, they use multiuser detection and decoding individually in a concatenated manner. According to simulation data, BIPCM performs better than MLPC with either decoder. Additionally, when the SCL approach is employed for decoding, SCMA systems using either the LTE turbo code or the WiMAX LDPC code outperform BIPCM and MLPC in terms of performance [19].

Paper Title: Bit-error rate analysis of low-density parity-check codes with generalised selection combining over a Rayleigh-fading channel using Gaussian Approximation

Authors: B.S. Tan, K.H. Li, K.C.

Low-Density Parity Check (LDPC) code is a linear error-correcting code. In wireless communication, for fifth generation LDPC is recommended due to its high throughput, low latency, low decoding complexity and rate compatibility. A sparse Tanner graph is used to build an LDPC code which is a capacity-approaching code means that there are practical constructions that allow the noise threshold for a symmetric memoryless channel to be set closer to the theoretical maximum (the Shannon limit). Rayleigh fading is a statistical model, assume that the magnitude of a signal transmitted through such a communication channel will vary randomly, or fade, according to a Rayleigh distribution — the radial component of the sum of two uncorrelated Gaussian random variables. In the low Signal to Noise ratio (SNR) region of Rayleigh fading channels, no diversity is extracted, and the coding gain is independent of the receive and temporal correlations, as only the transmit correlations affect the error probability. In this paper, density evolution (DE) is used to determine the SNR threshold, and Gaussian approximation (GA)is used to obtain the BER expression for generalized selection combining (GSC) with LDPC codes over Rayleigh-fading channels. GA methods simplify the analytical process while maintaining reasonable accuracy [20].

Paper Title: A High Performance Joint Detection and Decoding scheme for LDPC coded SCMA system

Author: Kaining Han* , Zhenbing Zhang, Jianhao Hu* , Jienan Chen

It is anticipated that the fifth generation (5G) wireless communication technology would enable a greater number of devices in the future. Smart sensors, mobile industrial automation, and vehicle connectivity will all be a part of 5G. Thus, one of the key objectives for the 5G system is huge connectivity. The Sparse Code Multiple Access (SCMA) is recommended as the contender of the 5G system in [21], even though the current mobile network systems may already accommodate five billion users. This would increase connectivity to enable several billion applications and hundreds of billions of machines.

SCMA can offer up to three times as many access users as other new code domain non-orthogonal multiple access technologies. Each user bit in the Orthogonal Frequency-Division Multiplexing Access (OFDMA) architecture of SCMA is distributed across several time-frequency Resource Blocks (RB). To simplify the complexity of the detection process while maintaining BER performance, many SCMA detectors are presented. However, a turbo structured Iterative SCMA Detection and LDPC Decoding (IDD) is proposed in [18] which demonstrates noticeable BER performance benefits with much more additional iterations in order to attain better Bit Error Rate (BER). The performance difference between SCMA and the single user orthogonal transmission system is still up to 2dB. Therefore, it is interesting to approximate single user performance in SCMA systems, and there is yet room for improvement for a higher performance SCMA detection.

Low Density Parity Check (LDPC) codes have been adopted for the digital video broadcasting (DVB-S2) and 802.11 (WiFi) protocols because they are known to approximate Shannon capacity . The iterative Belief Propagation (BP) method is used for the decoding of LDPC. To enhance system performance, the detection and decoding processes might be carried out in tandem and iteratively [22]. Joint Multiple Input Multiple Output (MIMO) detection and LDPC decoding are proposed in [23] and demonstrate a clear BER performance boost over conventional approaches. An approach for combining Low-density signature code division multiple access (LDS-CDMA) and LDPC decoding that is based on factor graphs is proposed in [24] and exhibits significantly improved BER performance than traditional CDMA systems.

In this research, they provide a Joint Detection and Decoding technique (JDD) based on factor graphs for LDPC coded SCMA systems. According to the findings of the simulation, the suggested JDD scheme outperforms the current individual scheme and the turbo structured iterative method by 2.6dB and 1.5dB, respectively. Additionally, the BER performance of the LDPC coded SCMA system can be approximated to that of the LDPC coded and QPSK modulated single user system utilizing the proposed JDD technique. We also suggest a joint detection and decoding system (RC-JDD) that exhibits a significant reduction in complexity with a tolerable loss in BER performance [25].

2.1 Summary

In this chapter, we have thoroughly discussed about OFDM, SC-FDMA, OFDMA, DS-CDMA, MC-CDMA, SCMA, Polar coded SCMA, low density parity check (LDPC) code and so on. According to this study, it is obvious that SCMA is superior to other modulation techniques due to its superior performance characteristics such as multiuser capacity with limited resources, supporting overloaded transmission, enabling reliable and low latency grant-free transmission, enabling flexible service multiplexing, the larger coding gain and better spectrum efficiency, and potential to combat the channel fading and MAI etc. Additionally, Polar code and LDPC code have brought a significant changes in the fifth generation (5G) wireless communication systems. These are simply an efficient capacity achieving error correcting codes which helps to improve the performance BER with respect to SNR for high rate data transmission and reduces various interferences. Thus we are motivated to work on LDPC coded SCMA systems.

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Chapter 3

Single carrier and Multicarrier Modulation

3.1 Single Carrier Modulation

Wireless communication is one of the most rapidly evolving and vibrant technological areas in the communication field. Wireless communication is the transmission of data over a long distance without the use of wires, cables, or other electrical conductors. In general, information is transmitted from transmitter to receiver over a limited distance in a communication system. Wireless Communication, which includes all procedures and forms of connecting and communicating between two or more devices using a wireless signal via wireless communication technologies and devices, allows the transmitter and receiver to be placed anywhere between few meters to thousand kilometres apart [1].

Wireless communication can be classified into two types such as single carrier modulation and multicarrier modulation. In single carrier modulation systems, only one signal frequency is used to transmit data symbols. On the other hand, the entire frequency channel is divided into many subscriber, and the high-rate data stream is divided into many low rate ones that are transmitted in parallel on subscribers in multicarrier modulation systems [2]. Many wireless communication systems use single-carrier modulation techniques, including conventional 1G, 2G, and 3G wireless communication systems, as well as the uplink of 4G wireless communication systems.

3.1.1 Advantages

The advantages of single carrier modulation:

1) Single-carrier modulation systems are less susceptible to frequency shift and phase noise, making time and frequency synchronization in wireless communication systems easier, particularly in paroxysmal point-to-point communication systems [3].

2) In single carrier modulation, the addition of a cyclic prefix (CP) allows for frequency domain channel equalization, allowing the simple single-tap equalizer to be used for channel equalization [3].

3) In single-carrier modulation systems, the peak to average power ratio (PAPR) is very low, which is beneficial for system stability and the use of low-cost devices in wireless communication system design [4].

3.1.2 Disadvantages

The disadvantages of single carrier modulation:

1) Single-carrier modulations are less capable of dealing with multipath fading channels than multicarrier modulations, resulting in lower spectral efficiency. Wireless communication systems are becoming increasingly broadband as technology advances; for example, current TD-LTE engages 20 MHz broadband, and future wireless communication systems will employ 100 MHz or more [4].

2) Higher bandwidths for single-carrier modulation systems result in smaller symbol intervals, which increases sensitivity to multipath fading channels and makes single-carrier modulation systems vulnerable to Inter Symbol Interference (ISI) [5].

To overcome the ISI, complex multi-tap equalizers must be used, resulting in high complexity and cost and multicarrier modulation systems are adapted due to their ability to combat multipath fading channels.

3.2 Multicarrier Modulation

Multicarrier modulation (MCM) is a technique for transmitting data over multiple sub-channels rather than the entire bandwidth in single carrier systems. The transmitted data stream is divided into several lower data rate data streams. In single carrier systems, the sub-channels have narrower bandwidths than wideband channels, and the symbol period on each sub-channel is increased. The MCM have been started in between late 1950s and early 1960s for military high frequency (HF) radio links. As multicarrier modulation systems divide the entire frequency band into many subcarriers, the symbol interval is longer in multicarrier modulations than in single-carrier modulations, that allows multicarrier modulation systems a stronger ability against ISI than single-carrier modulations [2].

3.2.1 Advantages

In wireless communication every modulation techniques have several advantages and disadvantages. Multicarrier modulation technique has some advantages in 3G, 4G, and 5G communication systems.

- Multicarrier modulation mitigates fading caused by data transmission over multipath or frequency-selective fading channels. Due to the reduced bandwidth, each sub-channel experiences flat fading. Additionally, the increased symbol period provides enhanced immunity to ISI [6].
- MCM added a cyclic extension or guard band to the data to overcome inter-symbol interference and increases the peak-to-average ratio of the signal.
- Multicarrier signals require longer intervals, result in, multicarrier modulation systems are less susceptible to time synchronization errors and more sensitive to frequency synchronization errors [6].
- As the spectrum of the subcarrier can be overlapped, it can provide greater spectral efficiency than single carrier modulation.

3.2.2 Disadvantages

Despite its benefits, the multicarrier modulation technique has drawbacks such as the need for synchronization with marginal conditions.

- High peak to average power ratio (PAPR) affects all multicarrier modulation systems. An increased peak to average power ratio required an increased system linearity to reduce distortion which increase the system cost [2].
- When High power signals passed through the amplifier would suffer from nonlinear distortion, which degrade system performance. As a result, only the downlink of LTE (long term evolution) uses multicarrier modulation, whereas the uplink of LTE uses single-carrier modulation [7].

Multicarrier modulation system includes Orthogonal Frequency Division Multiplexing (OFDM) and multi carrier-code division multiple access (MC-CDMA) using time division access in fourth generation of wireless communication [7].

3.3 Different types of Communication Systems based on Antenna types

There is a different category of multi antenna types as the communication system includes a transmitter and a receiver with distinguishable antenna allocations.

3.3.1 Single Input Single Output (SISO)

In MIMO configuration SISO (Single Input Single Output) is the elementary type of radio link. This is essentially a standard radio channel, as the transmitter and receiver both use a single antenna. The figure shown in figure 3.1. There is no variation and no extra processing is required. The integrity of a SISO system is its main advantage.

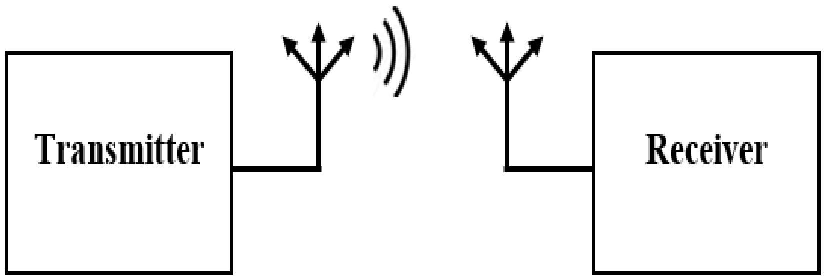

Figure 3. 1: Single Input Single Output

In terms of the various forms of diversity that may be used, SISO requires no processing but SISO channel has performance limitations. Interference and fading will have a greater impact on this system than a MIMO system with few form of diversity, and the channel bandwidth is limited by Shannon's theorem, with throughput dependent on channel bandwidth and signal-to-noise ratio.

3.3.2 Single Input Multiple Output (SIMO)

The Single Input Multiple Output (SIMO) occurs where the transmitter has a single antenna and the receiver has multiple antennas and which is also referred to as received diversity. It is frequently used to combat the effects of fading in receiver systems that receive signals from multiple independent sources. The figure shown in figure 3.2.

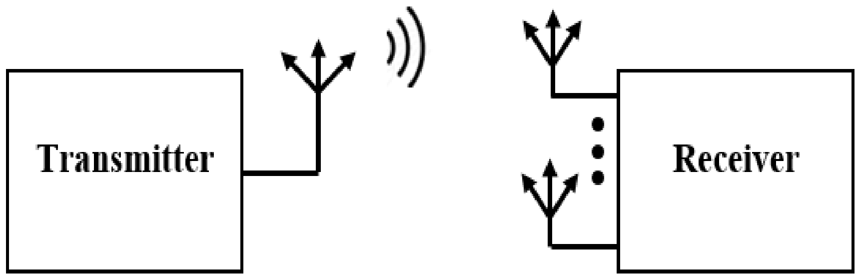

Figure 3. 2: Single Input Multiple Output

For many years, it has been used to combat the effects of ionospheric fading and interference with short wave listening / receiving stations. SIMO has the advantage of being relatively simple to implement, but it does have some drawbacks in that processing is required in the receiver. SIMO may be appropriate in many applications, but when the receiver is positioned in a mobile device, such as a mobile phone, the levels of processing may be limited by battery drain, cost and size.

3.3.3 Multiple Input Multiple Output (MISO)

MISO system, the same data is transmitted redundantly from both transmitter antennas. In this systems, there are multiple transmitting antennas and single receiving antenna and which is also referred to as transmit diversity. In The receiver can then receive the optimal signal, which it can then use to extract the required data. The benefit of using MISO is that the multiple antennas and redundancy coding/processing are transferred from the receiver to the transmitter. The figure shown in figure 3.3.

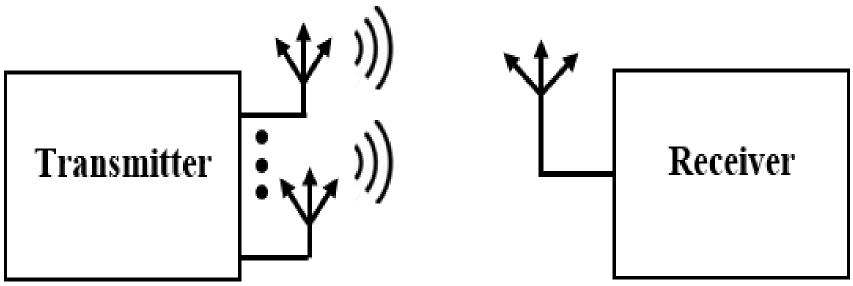

Figure 3. 3: Multiple Input Single Output

In cases like cell phone UEs, this can be a significant advantage in terms of antenna space and lowering the level of processing required in the receiver for redundancy coding. Because the lower level of processing necessitates less battery consumption, this has a positive impact on battery life, size, and cost.

3.3.4 Multiple Input Multiple Output (MIMO)

MIMO is based on the concept of transferring more data at the same time by using multiple antennas on the transmitter and receiver sides. The number of antennas can differ from one side to the other or be the same. The same data is transmitted through multiple antennas over the same path and bandwidth in a MIMO system. The figure shown in figure 3.4. To improve system performance, the MIMO system employs diversity techniques. MIMO has the potential to improve both channel robustness and channel throughput. By utilizing coding on the channels to separate data from the various paths, full benefit can be acquired from MIMO. This requires processing but adds channel robustness and data throughput capacity. Complex processing and switching are required to provide control over each antenna but complexity adds design time and cost.

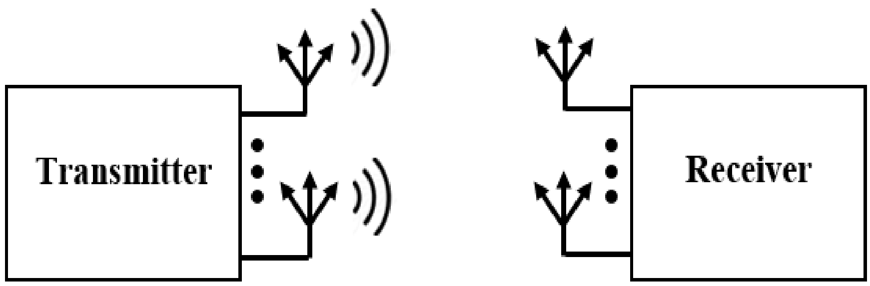

Figure 3. 4: Multiple Input Multiple Output

MIMO increases available bandwidth within a given spectral bandwidth and space by enabling spatial channelization and diversity. It improves signal range, non-line-of-sight (NLOS) or quasi-NLOS connectivity and reduces bit errors, power consumption, and interference. There are several advantages in a MIMO systems.

- Due to various diversity techniques such as time, frequency, and space, a MIMO-based system minimizes fading effects seen by information traveling from the transmitter to receiver end.
- The MIMO system offers higher Quality of service (QoS) with enhanced spectral efficiency and using multiple antennas to increase downlink and uplink throughput can result in higher data rates.
- MIMO based systems contribute to bit-error-rate (BER) reduction by utilizing advanced signal processing algorithms on received data symbols by multiple antennas.
- It also provides wide coverage by supporting a large number of subscribers per cell.

3.4 Orthogonal Frequency Division Multiplexing (OFDM)

In wireless communications, orthogonal frequency-division multiplexing (OFDM) is a type of digital transmission and method of encoding digital data on multiple carrier frequencies. OFDM is a frequency-division multiplexing (FDM) scheme developed by Robert W. Chang in 1966. OFDM has evolved into a popular wideband digital communication scheme, with applications including digital television and audio broadcasting, digital subscriber line (DSL) internet access, wireless networks, power line networks, and 4G/5G mobile communications [8]. OFDM is widely used, particularly in broadband wireless communication systems, due to its resistance to multipath fading and ability to deliver high data rates with low computational complexity. OFDM is highly spectrally efficient, allowing for high data rate transmission while maintaining low receiver complexity even in a dispersive radio channel [9].

In OFDM modulation, a broadband channel is divided into multiple parallel narrowband sub-channels, in which pulse shapes are square waves, each carrying a low data rate stream, resulting in a high data rate transmission. Before extracting the transmitted data, the OFDM receiver detects the channel and corrects distortion on each sub-channel. Each frequency in OFDM is an integer multiple of the fundamental frequency. This ensures that sub-channels do not interfere with each other even when they overlap [10]. The figure shows in figure 3.5 where the vertical axis represents the magnitude of the spectrum and the horizontal axis represents the frequency.

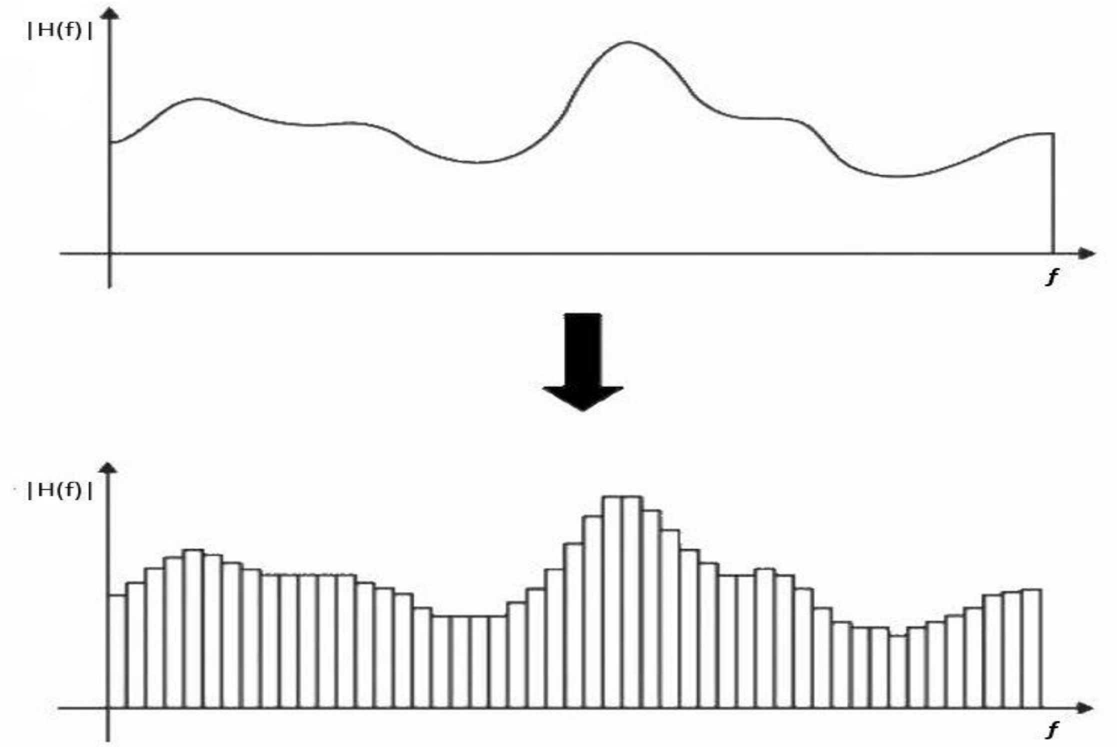

Figure 3. 5: A broadband channel divided into many parallel narrowband channels [11]

The overlapping of sub-channels in OFDM system has shown in figure 3.6.

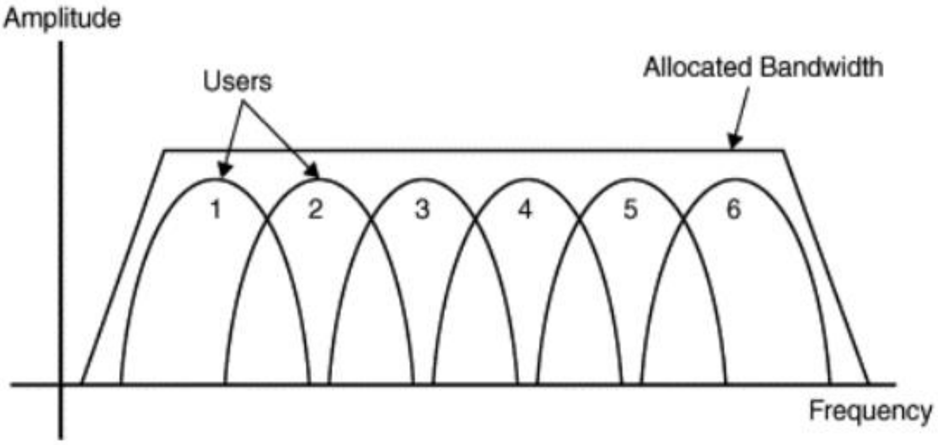

Figure 3. 6: Overlapping sub-channels [11]

In an OFDM transmitter, a bank of quadrature amplitude modulation (QAM) encoders first maps the bits into complex symbols, which are then fed into an inverse fast Fourier transform (IFFT) to ensure the orthogonality of the sub-channels. The output is then converted from parallel to serial and modulated onto a carrier for wireless transmission over the air. In OFDM system, inter symbol interference (ISI) and inter carrier interference (ICI) are identified. ISI is the crosstalk between signals within the same sub-channel of successive Fast-Fourier Transform (FFT) frames separated in time by the signalling interval. ICI is the crosstalk between adjacent sub-channels or frequency bands of the same FFT frame. To eliminate ISI and ICI, guard interval is used and cyclic prefix is added in OFDM system to combat against multipath fading. Demodulation is based on Fast Fourier Transform algorithms. The block diagram of OFDM transmission system is shown in figure 3.7.

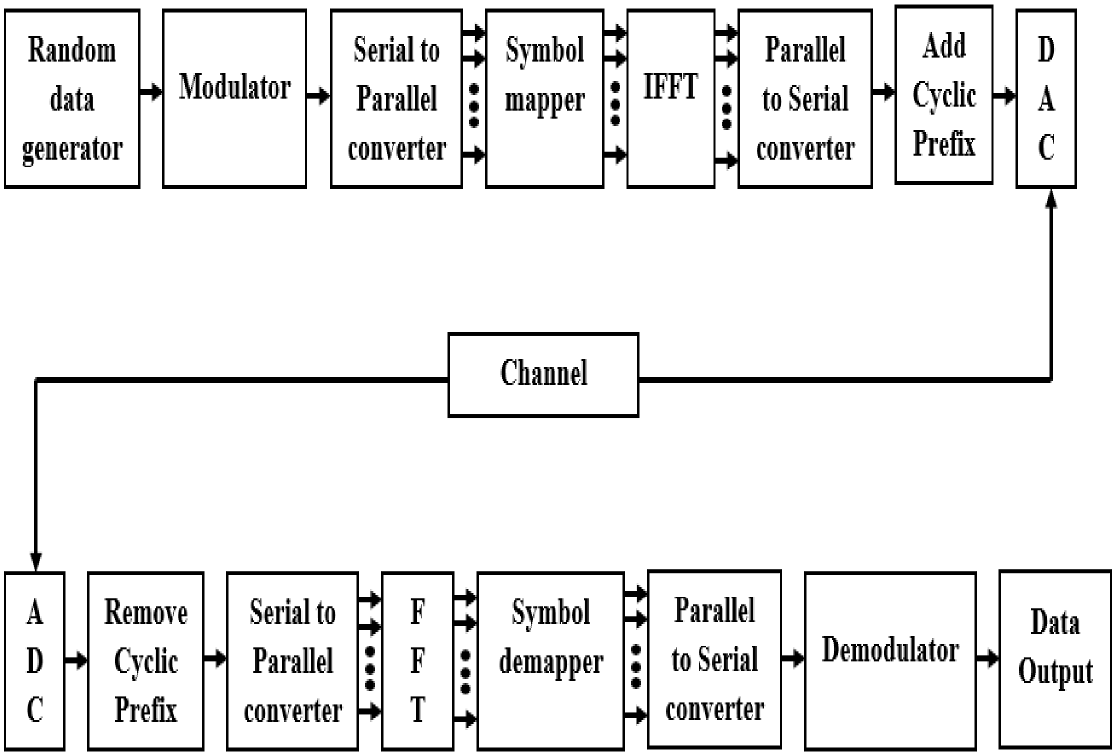

Figure 3. 7: Block Diagram of OFDM Transmission System [12]

3.4.1 Advantages of OFDM

OFDM has been used in many high data rate wireless systems due to the numerous advantages it provides.

1) Immunity to Selective Fading: As OFDM divides the overall channel into multiple narrowband signals that are affected individually as flat fading sub-channels, it is more resistant to frequency selective fading than single carrier systems [13].

2) Spectrum Efficiency: A significant advantage of using close-spaced overlapping sub-carriers is that it makes efficient use of the available spectrum [14].

3) Resilience to Interference: Interference on a channel may be bandwidth limited, and thus will not affect all sub-channels. This implies that not all of the data has been lost[13].

4) Resilient to Inter Symbol Interference: OFDM also has the advantage of being very resistant to inter-symbol and inter-frame interference. This is due to the low data rate on each sub-channel.

5) Simpler Channel Equalization: The complexity of the channel equalization that had to be applied across the entire channel was one of the issues with code division multiple access (CDMA) systems. OFDM has the advantage of making channel equalization much simpler by using multiple sub-channel [13].

6) Resistant to Narrow-Band Effect: It is possible to recover symbols lost due to frequency selectivity of the channel and narrow band interference by using appropriate channel coding and interleaving. Not all of the data has been lost [14].

3.4.2 Disadvantages of OFDM

While OFDM has been widely used, there are a few drawbacks to its use that must be addressed when considering its use.

1) High Peak to Average Power Ratio: An OFDM signal has an amplitude variation similar to noise and a relatively large dynamic range, or peak to average power ratio. This has an impact on Radio-frequency (RF) amplifier efficiency because the amplifiers must be linear and accommodate large amplitude variations, which means the amplifier cannot operate at a high efficiency level [13].

2) Synchronization Problem: In OFDM system, symbol synchronization and frequency synchronization problems occur. Symbol synchronization occurs due to timing errors and carrier phase noise. In Frequency synchronization problem, sampling frequency synchronization and carrier frequency synchronization happened [13].

3) Sensitive to carrier offset and drift: Another drawback of OFDM is that it is susceptible to carrier frequency offset and drift. Systems with a single carrier are less sensitive.

The problem of PAPR is that it increased the complexity of analog to digital converter (ADC) and digital to analog converter (DAC) and reduced the efficiency of the RF amplifier. This problem can be solved by signal distortion techniques, which reduce the peak amplitude simply by non-linearly distorting OFDM signals. Different multiple access techniques are adopted to avoid this problem. OFDM can be combined with multiple access using time, frequency or coding separation of the users. Frequency-division multiple access (FDMA) is achieved in orthogonal frequency-division multiple access (OFDMA) by assigning different OFDM sub-channels to different users. OFDMA supports differentiated quality of service by assigning a different number of subcarriers to different users in the same way that code division multiple access (CDMA) does, avoiding complex packet scheduling or Media Access Control schemes. OFDM is combined with CDMA spread spectrum communication in multi-carrier code-division multiple access (MC-CDMA) for coding separation of the users. Co-channel interference can be reduced, allowing for simpler manual fixed channel allocation (FCA) frequency planning or the avoidance of complex dynamic channel allocation (DCA) schemes.

3.5 Multiple Access Techniques

In wireless communications systems, it is frequently desirable for the subscriber to be able to send information to the base station while simultaneously receiving information from the base station. A cellular system divides any given area into cells, with each cell having a mobile unit that communicates with a base station. The primary goal of cellular system design is to increase channel capacity, i.e. to handle as many calls as possible in a given bandwidth while maintaining a sufficient level of service quality. Multiple access techniques are used to allow a large number of mobile users to share the allocated spectrum in the most efficient way possible. As the spectrum is limited, sharing is required to increase the capacity of a cell or over a geographical area by allowing different users to use the available bandwidth at the same time. And it must be done in such a way that the quality of service does not deteriorate among existing users. There are different types of multiple access techniques. Primarily, multiple access techniques can be classified into orthogonal multiple access (OMA) and non-orthogonal multiple access (NOMA) methods. Orthogonal multiple access can be sub-divided into Frequency Division Multiple Access (FDMA), Time division Multiple Access (TDMA), Code Division Multiple Access (CDMA). Frequency Division Multiple Access has different methods such as Single Carrier Frequency Division Multiple access and CDMA has multi carrier (MC) CDMA method. The hierarchical order of multiple access scheme is shown in figure 3.8.

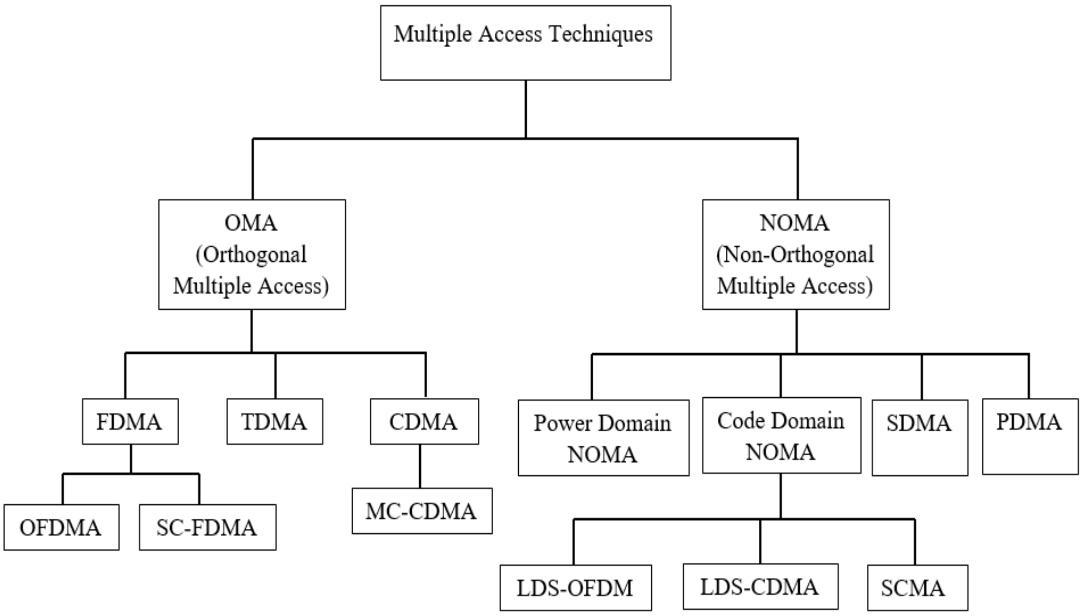

Figure 3. 8: Hierarchy of Multiple Access Techniques

In NOMA, there are several category such as power domain NOMA, code domain NOMA, spatial division multiple access (SDMA), and partial division multiple access (PDMA). Code domain NOMA can be sub divide into Low Density Signature (LDS) OFDM, LDS-CDMA, and spare code multiple access (SCMA).

3.5.1 Orthogonal Multiple Access (OMA) vs Non-Orthogonal Multiple Access (NOMA)

The fifth generation (5G) of wireless communication technologies is anticipated to fulfil previously unrecognized standards. Non-orthogonal multiple access (NOMA), one of the possible methods for solving these difficulties, has been heavily researched recently. The main characteristic that sets NOMA apart from the family of traditional orthogonal multiple access (OMA) schemes is its ability to handle more users than there are orthogonal resource slots for through the use of non-orthogonal resource allocation. Multiple users are allotted to orthogonal radio resources in the time-, frequency-, and code-domains or to their combinations in typical OMA systems like FDMA, TDMA, CDMA, and OFDMA used for 1G, 2G, 3G, and 4G, respectively. In FDMA, each user specifically transmits a distinct, user-specific signal across a distinct frequency resource, allowing the receiver to easily recognize all users' data in their corresponding frequency bands.

Similar to TDMA, each user is given an exclusive time slot, making it simple to discriminate between the various users' signals at the receivers in the time domain. Multiple users can share the same time-frequency resources in CDMA, and various users' transmitted symbols may be translated into orthogonal spreading sequences like Walsh-Hadamard codes. For multiuser detection, a low-complexity decorrelation receiver can be employed (MUD). The radio resources are orthogonally divided in the time-frequency grid in OFDMA, which can be thought of as a clever integration of FDMA and TDMA. Since there is theoretically no interference between users in OMA systems thanks to orthogonal resource allocation, various users' signals can be separated using low-complexity detectors with linear complexity.

However, the quantity of orthogonal resources available in traditional OMA schemes severely limits the maximum number of supportable users, which becomes a hard constraint when huge connection is needed for 5G. Additionally, it has been theoretically demonstrated that NOMA is capable of attaining the multi-user capacity with the help of time-sharing or rate-splitting if necessary, but OMA is unable to always achieve the maximum feasible sum-rate of multi-user wireless systems. NOMA has lately been looked into as a design alternative to get over OMA's aforementioned constraint.

The main characteristic that sets NOMA apart from other resource allocation techniques is its ability to handle more users than there are slots for orthogonal resources. The sophisticated inter-user interference cancellation may be used to do this at the expense of a higher receiver complexity, such as computational complexity with polynomial or exponential order. Additionally, it is important to keep in mind that even when using OMA methods, the time-domain signals are masked due to their convolution with the dispersive channel impulse response (CIR). Additionally, the family of CDMA systems, which support more than N_c users at the expense of inter-user interference, rely on more non-orthogonal sequences than the number of chips N_c in a sequence. Strong multiuser detectors are the only way to effectively minimize such interference.

Consequently, the NOMA idea is tempting. The NOMA family of schemes can essentially be split into two groups: code-domain NOMA and power-domain NOMA. When using power-domain NOMA, users are given varied power levels based on the quality of their channels while sharing the same time-frequency-code resources. Power-domain NOMA utilizes the power-difference between users on the receiver side to discriminate between users based on sequential interference cancellation.

The capacity analysis shows that achieving a greater transmission rate for NOMA than OMA is doable. In particular, the key benefits of NOMA over traditional OMA can be summed up as follows:

- Improved spectral efficiency and cell-edge throughput:

  Both in the power-domain and the code-domain of NOMA, users share the time-frequency resources non-orthogonally. As mentioned above, although both OMA and NOMA are capable of obtaining the maximum attainable sum capacity in the uplink of AWGN channels, NOMA enables a more equal user fairness. Furthermore, in the downlink of AWGN channels, NOMA has a greater capacity bound than OMA. OMA is capable of reaching the highest achievable sum capacity in the downlink of multi-path fading channels subject to inter-symbol interference (ISI), however if the CSI is only known at the downlink receiver, NOMA depending on MUD is optimal while OMA remains suboptimal.

- Massive connectivity:

  The number of supportable users/devices is not strictly constrained by the availability of orthogonal resources, according to NOMA's non-orthogonal resource allocation. Therefore, NOMA has the ability to provide enormous connectivity since it can considerably increase the number of simultaneous connections in rank-deficient settings.

- Low transmission latency and signalling cost:

  In traditional OMA that relies on access-grant requests, a user must firstly submit the base station a scheduling request (BS). The BS then responds with a clarity to transmit signal in the downlink channel in response to this request, scheduling the user's uplink transmission. As a result, there will be a significant transmission latency and a high signalling overhead, which is unacceptable in the case of widespread 5G-style connectivity. As a result, there will be a significant transmission latency and a high signalling overhead, which is unacceptable in the case of widespread 5G-style connectivity. In LTE, the access grant process takes around 15.5 milliseconds before the data is transferred. As a result, there will be a significant transmission latency and a high signalling overhead, which is unacceptable in the case of widespread 5G-style connectivity. In LTE, the access grant process takes around 15.5 milliseconds before the data is transferred.

- Relaxed channel feedback:

  Because CSI feedback is solely used for power allocation in power-domain NOMA, the necessity for channel feedback will be eased. Therefore, exact immediate CSI information is not required. Therefore, as long as the channel does not change quickly, providing limited-accuracy outdated channel feedback associated with a given maximum inaccuracy and delay will not significantly hinder the achievable system performance, regardless of whether fixed or mobile users are supported.

NOMA has being intensively explored with a view to employment in 5G as a promising solution, given the aforementioned notable advantages.

3.5.2 Orthogonal Frequency Division Multiple Access (OFDMA)

High data rate services, multimedia applications, and high quality information streams in general are currently in high demand and will remain so in the near future. Wireless systems are viewed as a viable and appealing solution for providing high data rate communications, particularly to mobile users. In wireless communication, orthogonal frequency division multiplexing has drawbacks. In order to mitigate the negative effects of frequency-selective multi-path fading and efficiently contrast the inter-symbol and inter-carrier interferences (ISI and ICI) Orthogonal Frequency Division Multiple Access (OFDMA) scheme was adapted by IEEE 802.16 family of standards [15].

OFDMA is a multi-user implementation of the digital modulation scheme OFDM. OFDM divides the signal into independent subcarriers, and these closely spaced orthogonal subcarriers carry the data. Each subcarrier's data is separated into several parallel data streams or channels. OFDMA is a modulation and access technique that combines TDMA and FDMA technologies. OFDMA improves spectral efficiency by saving half of the allocated bandwidth. OFDMA allows users to assign each subcarrier independently, allowing for resource flexibility and the support of mobile applications. The multicarrier nature of OFDMA transmission yields better results when combined with adaptive techniques to achieve higher efficiency in terms of error rate and throughput. The LTE downlink air interface is based on OFDMA, which provides good flexibility and performance at a reasonable complexity [16].

3.5.3 OFDMA System Model

In OFDMA transmitter, at first, X symbols/second data are transmitted, and the data symbols are passed through a serial to parallel converter, with the data rate on each K line being X/K symbols [16]. The input data stream is then mapped to each carrier using various modulation schemes such as QPSK, 16-QAM, 64QAM, and so on. The Inverse Fast Fourier Transform (IFFT) is then used to find the corresponding Time wave form, which means that M symbols are sent to an Inverse Fast Fourier Transform that performs N-point IFFT operation. The output is N time samples [12]. The Guard interval is then introduced at the start of each sample, which is known as the addition of cyclic extension in the prefix of length C_P to overcome the effects of frequency-selective channel fading. The output sample length is then N+C_P. The cyclically extended symbols are converted to serial and then transmitted via a channel [17] .After that, the transmitted signal is subjected to a channel model. The model allows to control the signal-to-noise ratio and multipath. The signal-to-noise ratio is determined by adding a known amount of white noise to the transmitted signal, which is referred to as Additive white Gaussian noise (AWGN.) The receiver operates in the opposite direction of the transmitter. The transmitted signals that pass through the channel are then converted to parallel by a serial to parallel converter, and the cyclic extension is also removed. The signals are processed by an N-point Fast Fourier Transform FFT), which converts time domain signals to frequency domain signals. The signal is then demapped and converted from parallel to serial using the Parallel to serial convert block, with the resultant signal being a M sample output [18]. The system model of OFDMA shown in figure 3.9.

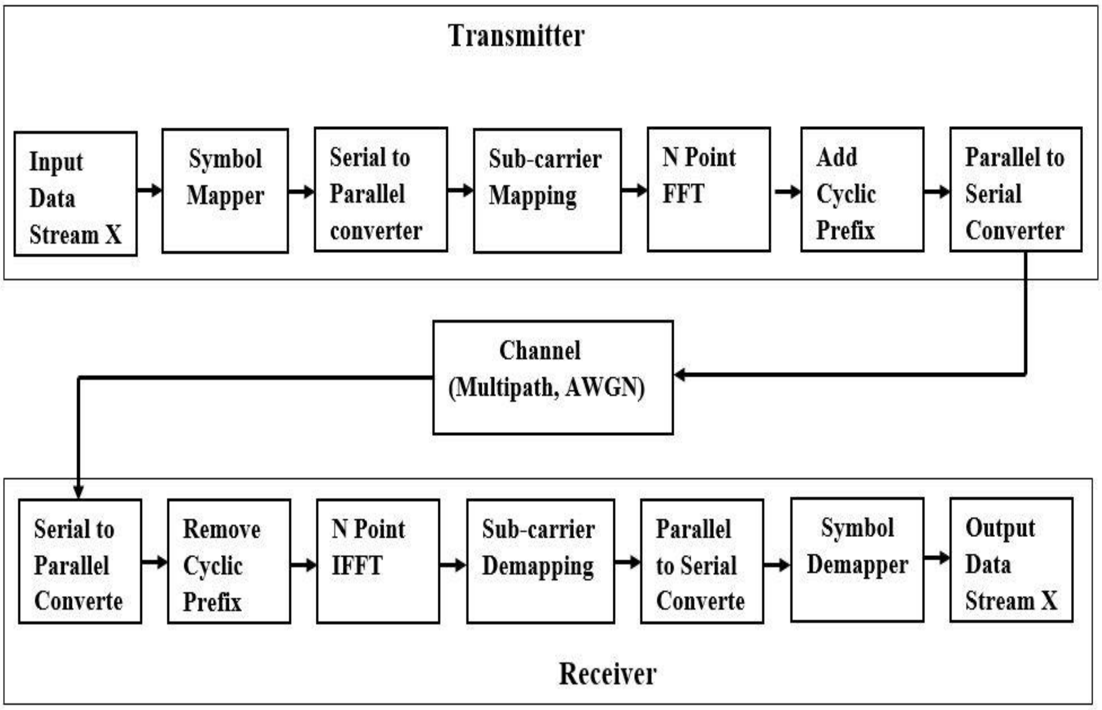

Figure 3. 9: Block Diagram of OFDMA System Model [19]

3.5.4 Advantages of OFDMA System

OFDMA system has been used in many high data rate wireless systems, because it provides numerous advantages.

1) OFDMA system allows for simultaneous low-data-rate transmission from multiple users, and avoids the use of a pulsed carrier [18].

2) It reduces maximum transmission power for users with low data rates and provides shorter delay and constant delay [18].

3) OFDMA system improves OFDM robustness to fading and interference and oppose against narrow band interference [20].

4) It has the ability to deploy across multiple frequency bands with minimal changes to the air interface.

5) Interferences from neighbouring cells are averaged using various basic carrier permutations between users in different cells. Interferences within the cell are averaged using cyclic permutations in allocation [20].

6) It provides frequency diversity by dispersing the carriers across the available spectrum.

3.5.5 Disadvantages of OFDMA System

Like other modulation techniques, OFDMA has several drawbacks.

1) The high PAPR of OFDMA is a significant disadvantage. Each sample at the output of the N-point IDFT appears as the sum of M independent variables and is thus asymptotically Gaussian, explaining the high envelope variations of OFDMA [18].

2) Subcarrier permutation and depermutation rules for allocation and deallocation to sub-channels are complex. Unlike OFDM, this complicates the transmitter and receiver algorithms for data processing/extraction. When an OFDMA signal passes through a nonlinear RF amplifier, the BER (Bit Error Rate) is also increased [20].

3) OFDMA requires very precise time/frequency/channel equalizations between users. Managing co-channel interference from neighbouring cells in OFDM is more difficult than in CDMA. Dynamic channel allocation and advanced coordination among adjacent base stations would be required [20].

4) Fast channel feedback information and adaptive subcarrier assignment are more complicated than CDMA fast power control.

3.5.6 Code Division Multiple Access (CDMA)

With the use of pre-assigned signature sequences, many users can simultaneously and asynchronously access a channel using the multiplexing technique known as code division multiple access (CDMA). A possibility for supporting multimedia services in mobile radio communications has recently been the CDMA method, because

- It is equipped to handle the asynchronous nature of multimedia data transfer on its own.

- with the purpose of providing more capacity than traditional access methods like time division multiple access (TDMA) and frequency division multiple access (FDMA)
- To overcome the frequency selectivity of the hostile channel.

3.5.7 Direct Sequence Code Division Multiple Access (DS-CDMA)

Using the provided spreading code in the time domain, the DS-CDMA transmitter distributes the original data stream. The cross correlation feature of the spreading codes determines the capacity to suppress multi-user interference. Additionally, a frequency selective fading channel is distinguished by the superimposition of many signals with various time-domain delays. As a result, the auto-correlation properties of the spreading codes affect the capacity to identify one component from other components in the composite received signal.

3.5.8 Multi Carrier Direct Symbol Code Division Multiple Access (MC-DS-CDMA)

Utilizing a specific spreading code in the time domain, the multicarrier DS-CDMA transmitter spreads the serial to parallel converted data streams so that the resulting spectrum of each subcarrier can satisfy the orthogonality criteria with the least amount of frequency separation. Because the addition of OFDM signaling to DS-CDMA is effective in establishing a quasi-synchronous channel, this approach was initially proposed for an uplink communication channel.

3.5.9 Multi Carrier Code Division Multiple Access (MC-CDMA):

A promising technique for the next wireless communication networks is the MC-CDMA protocol [21]. Future wireless communication will require a system that can accommodate numerous users and deliver high data rates [22, 23]. A form of multiple access called MC-CDMA makes use of the advantages of both CDMA and OFDM protocols. While spread spectrum technology effectively makes use of the scarce spectrum, the multi-carrier component lowers multipath fading and ISI. The resistive channel will be created by the high data rate transmission. By dividing the high data rate data into parallel subcarriers with low data rates, the multi-carrier component will be able to solve this issue [24]. High spectral efficiency is provided via carrier overlapping. The power spectrum of the transmitted MC-CDMA signal is displayed in Figure 3.10.

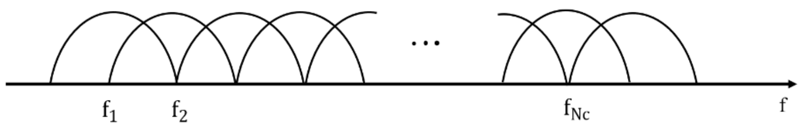

Figure 3. 10: Power Spectrum of MC-CDMA Signal [22]

3.5.10 MC-CDMA System:

Because just one carrier signal is modulated in conventional CDMA, the overall signal may be corrupted if the signal experiences any multipath fading. Even when some subcarriers are impacted by multipath fading, the receiver is still able to receive information accurately thanks to multiple carrier modulation techniques like MC-CDMA [25]. Each serial data symbol $b^j(i)$ from user j in Figure 3.11, which shows the MC-CDMA block diagram, is transformed into a parallel data stream, spread over frequency domain using a user-defined spreading code v_m, each of which is linked to a subcarrier, and then transformed into time domain using an inverse fast fourier transform (IFFT).

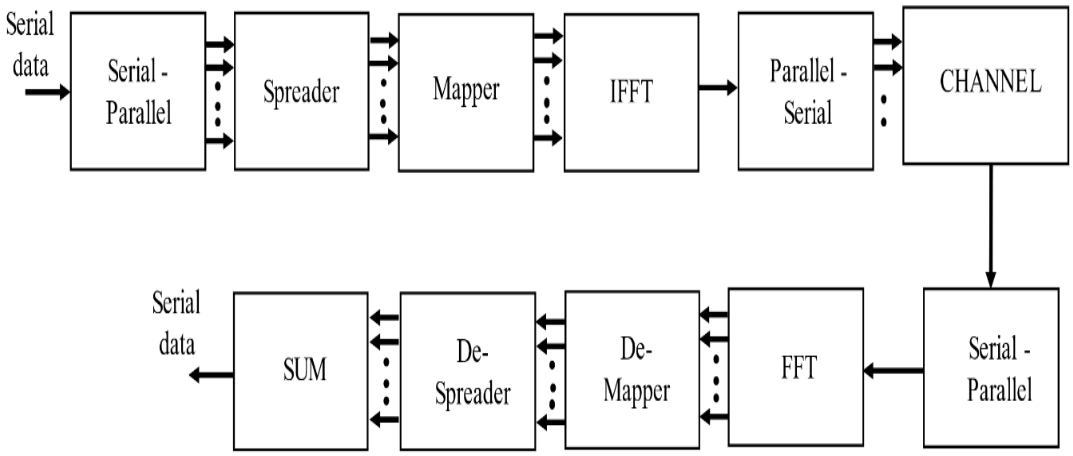

Figure 3. 11: Block Diagram of MC-CDMA System [24]

Eventually, the signal is returned to serial form and modulated before being sent through the mathematically determined communication channel in equation (1). Data are converted to parallel streams at the receiver, and each block containing spread signals is then broken down into subcarriers using the Fast Fourier Transform (FFT), which is then turned into the frequency domain for dispreading to recover the original data.

The transmitted signal for j^{th} user is written as

$$S_{MC}^{j}(\mathrm{t}) = \sum_{i=-\infty}^{\infty} \sum_{m=1}^{G_{MC}} b^{j}(i)\, v_{m}^{j}.\{2\pi(f_0 + \mathrm{m}\Delta \mathrm{f})\mathrm{t}\} \tag{3.1}$$

Where $\Delta f = \frac{1}{T_s}$ is the subcarrier. v_m is the spreading code at m subcarrier and $b^j(i)$ is the original data stream at the time i [26].

3.5.11 MC-CDMA Transmitter:

The schematic diagram of the Multi Carrier-CDMA transmitter system is shown in Figure 3.12. Walsh Hadamard code is used to spread the input binary data, and after that, these data are sent into a serial-to-parallel converter to transform the high-speed serial stream into low-speed parallel streams. Depending on the suitable modulation methods, such as Binary PSK or Quadrature PSK or Binary PSK or Quadrature PSK, Binary PSK, and Quadrature PSK, Binary PSK, and Quadrature PSK.

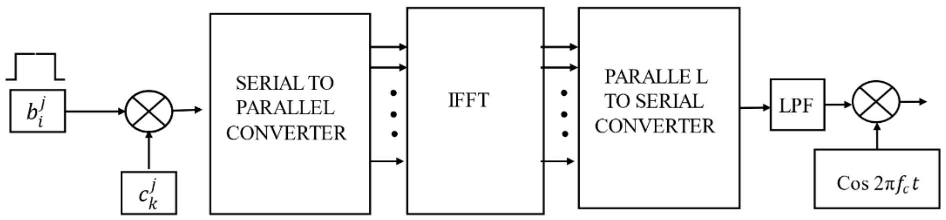

Figure 3. 12: Block Diagram of MC-CDMA Transmitter [26]

3.5.12 MC-CDMA Receiver:

Data are converted to parallel streams at the receiver, and each block containing spread signals is then broken down into subcarriers using the Fast Fourier Transform (FFT), which is then turned into the frequency domain for dispreading to recover the original data. The MC-CDMA transmitter for Binary Phase Shift Keying is modeled by the equation (BPSK). Data are separated into many parallel data streams or channels, one for each subcarrier, when a single carrier signal is split into multiple subcarrier signals [27]. The block diagram of MC-CDMA is shown in figure 3.13.

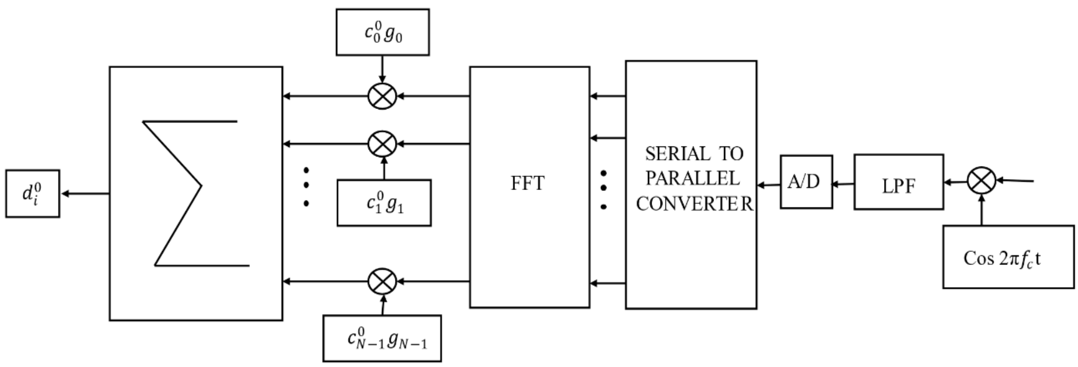

Figure 3. 13: Block diagram of MC-CDMA Receiver [26]

Then, each subcarrier signal is modulated using a low symbol rate so that the combined data rate of all of these subcarrier signals is the same as that of a standard single carrier. This technique's basic premise is that multipath fading is less of an issue for signals with longer symbol durations than it is for signals with shorter symbol durations, such as CDMA.

3.5.13 Advantages of MC-CDMA:

1) Whereas MC-CDMA combines CDMA and OFDM, we can benefit from both schemes' advantages [28].

2) As a potent transmission method, MC-CDMA, which combines OFDM and code-division multiple access (CDMA), has attracted interest [29].

3) The performance of the bit error rate (BER) is enhanced by the MC-CDMA method, which distributes the data symbols in the frequency domain and transmits them on various subcarriers, hence preventing frequency selective fading [28].

4) The system's MAI output will have a significant impact on the BER performance of the MC-CDMA system. The spreading code given to each user affects the level of MAI. To achieve good correlation features, codes should be utilized [30].

3.5.14 Disadvantages of MC-CDMA:

1)The performance and capacity of CDMA systems are diminished by self-interference (SI) and multi-user interference (MUI), which are both caused by MPI and MAI [31].

2) MC-CDMA systems have a high peak average power ratio (PAPR) [32].

3) High PAPR requires that the RF power amplifiers operate in a very wide linear zone; otherwise, the signal peaks will migrate into the power amplifier's nonlinear region, causing signal distortion.

3.6 Conclusion

In wireless communication system, single carrier and multicarrier modulation provides high speed data transmission, low complexity, reduce bit error rate, provides higher channel capacity, higher spectral efficiency. Due to several drawbacks of OFDM system different multiple techniques are adapted such as high PAPR, channel and frequency synchronization problems. OFDMA and MC-CDMA methods are enable to reduce the adverse effects of high PAPR, channel complexity, ISI, ICI and improves the performance of channel synchronization, multi-path fading problems and reduces the BER of the systems. But OFDMA and MC-CDMA also has some drawbacks. To avoid those drawbacks sparse code multiple access (SCMA) technique is introduced in wireless communication system. Sparse code multiple access techniques is discussed in chapter 4.

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Chapter 4

Sparse Code Multiple Access Schemes

4.1 Introduction

Next-generation cellular systems are expected to support a diverse set of vertical industries, including e-health, smart homes/cities, connected autonomous vehicles, and future factories. While this results in ubiquitous digital data services available anywhere and at any time, the explosive growth of communication devices and applications results in increasingly congested spectrum, which is one of the major challenges in the design of 5G communication networks and beyond. Multiple access, as one of the fundamental techniques of wireless communication, seeks to enable multiple users to access limited resources concurrently and effectively. Multiuser communication systems primarily employ orthogonal multiple access (OMA) schemes, in which multiple users are orthogonal to each other in terms of a specific type of resource. Non-orthogonal multiple access (NOMA) is one of the key enabling technologies for the physical layer of 5G systems, which can not only provide higher spectral efficiencies but also support a greater number of connected subscribers than existing systems [2]. Two promising NOMA schemes, particularly power-domain NOMA (PD-NOMA) and sparse code multiple access (SCMA), are currently being considered for 5G systems and have received significant attention from both academia and industry[3]. Sparse code multiple access (SCMA) was proposed as a disruptive code domain NOMA scheme by H. Nikopour and H. Baligh in 2013 [3]. SCMA is a generalized multiple access scheme based on low-density signature CDMA (LDS-CDMA), which is a subset of CDMA in which several bits from each user are mapped to a symbol before sparse sequence spreading [4]. As compared to low density signature (LDS) CDMA, SCMA system combines the advantages of low receiver complexity and improves the performance [5]. In LDS, incoming bits are mapped to a QAM symbol, and QAM symbol repetitions are transmitted via subcarriers in accordance with the designed signature. On the other hand, in SCMA, incoming bits are directly mapped to multi-dimensional complex code-words from a predefined codebook [6]. In SCMA system using a sparse spread pattern, code-words are overlaid non-orthogonally in the same time-frequency resources. In the receiver terminal, this sparse feature is used to perform low-complexity multiuser joint detection, after that the bits are restored by the channel decoder and message passing algorithm (MPA) is adopted to eliminate inter user interference (IUI) [7]. The main feature of SCMA is that the number of non-orthogonally overlaid code-words can be several times greater than the number of resources. When compared to OFDMA in 4G communication, SCMA can serve more users simultaneously while using the same number of resources, hence the overall capacity of the system can be increased.

4.2 Background Study of SCMA

Future 5G wireless networks are expected to support massive connectivity, lower latency, higher throughput, and lower controlling signal overhead. NOMA has the advantage of higher resource utilization which is more promising in 5G networks than traditional orthogonal multiple access (OMA) techniques such as code division multiple access (CDMA) and orthogonal frequency division multiple access (OFDMA) used in current networks. Reza Hoshyar first proposed sparse spreading, known as Low Density Signature (LDS), in response to the design of CDMA chip sequences [4]. LDS is a significant case of multi-carrier CDMA that includes a few non-zero elements in a long spreading signature. This sparsity property can reduce the complexity of the multi-user detection algorithm known as the Message Passing Algorithm (MPA) [8]. The capacity of an LDS-OFDM system, which combines LDS with Orthogonal Frequency Division Multiplexing (OFDM), is demonstrated to be superior to that of OFDMA [9]. Due to the low density of LDS sequences, the message passing algorithm (MPA) can be reused in the complex domain for iteratively joint multi-user detection with near optimal MAP performance. A CDMA encoder repeats a QAM symbol to a sequence of complex symbols by using CDMA signature. Instead of simply repeating the QAM symbol in CDMA, SCMA provides significant shaping gain with the multi-dimensional constellation design [10]. SCMA code-words are sparse because, only a few number of dimensions are used to transmit data, like LDS. The non-zero dimensions in the SCMA codebook correspond to the subcarriers in use. The earlier researches of SCMA are mainly focused on codebook design, low-complexity decoding, resource allocation, capacity analysis, blind detection and other topics. Researchers compared the capacity of the SCMA system to that of the LDS system [11] and analyse the capacity of the downlink massive MIMO MU-SCMA system in the capacity analysis area [12]. With the goal of minimizing error probability, novel CBs for both Rayleigh and Gaussian channels based on Star-QAM constellations have been developed [13]. CBs with golden angle modulation (GAM) constellations have excellent error rate performances in both uplink and downlink Rayleigh fading channels [14]. A low complexity construction algorithm for near-optimal CBs has recently been developed [15]. Due to the codebook sparsity, multiuser signals can be detected and recovered efficiently using the message passing algorithm (MPA), whose error rate performance is comparable to that of the maximum a posteriori (MAP) detector [16]. The belief messages are passed along the edges of the corresponding factor graph in message passing algorithm, which is correlated with the sparse codebooks of an SCMA system.

4.3 SCMA Encoder

An SCMA system mainly consists of two segments: i) SCMA encoder and ii) SCMA decoder.

SCMA encoder is defined as a mapping binary sequence to multi-dimensional complex constellation: F: $\mathbb{B}^{log_2(M)} \rightarrow \boldsymbol{\mathcal{X}}$, $\boldsymbol{x} = F(\boldsymbol{b})$ where $\boldsymbol{\mathcal{X}} \in \mathbb{C}^K$ with cardinality $|\boldsymbol{\mathcal{X}}| = M$. K dimensions are corresponding to K different orthogonal resources and sparse vector $\mathbf{x}$ is the K-dimensional complex code-word with only N < K nonzero entries. Users can't transmit data through the subcarriers represented by the other $\mathrm{N} - \mathrm{K}$ zero entries. Theoretically, each user can be allocated to more than one codebook, and each codebook can be utilized by more than one user generally. Assuming J synchronous users are multiplexing over K shared orthogonal resources, such as K time slots or orthogonal frequency division multiplexing (OFDM) tones, and each user employs one SCMA layer. Forward error control (FEC) coding schemes can be polar codes or low-density parity-check (LDPC) codes, both of which have recently been adopted for 5G. The coded bits are mapped to a K-dimensional complex code-word by each SCMA modulator/encoder, and the resulting J code-words comprise an SCMA block as shown in SCMA transmission system in figure 4.1 where $J = 6$ and K= 4.

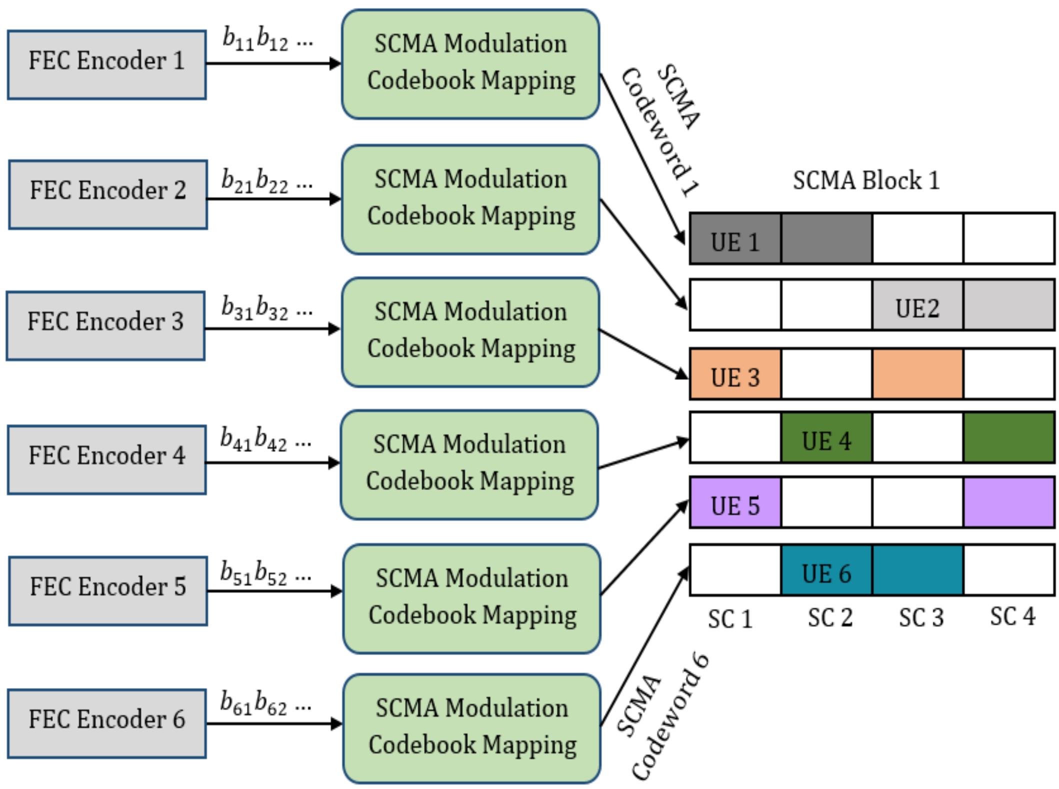

Figure 4. 1: System Model of Sparse Code Multiple Access [6]

The multi-user code-words in each SCMA block are either multiplexed over the air in uplink multiple access channel (MAC) transmissions or superimposed at the downlink broadcast channel transmitter (BC). Because each SCMA block uses K resources to transmit code-words, then the overloading factor is J/K. To recover colliding code-words, the receiver performs multi-user detection.

4.3.1 Codebook Mapping

The most important aspect of the SCMA encoder is the codebook design. The goal is to create a multidimensional lattice constellation with dimensional dependency and power variation while keeping a large minimum Euclidean distance. In SCMA codebook design mapping matrix, constellation point and multi-dimensional constellation design and constellation factor operator are the significant factor [17]. The number of layers interfering at each subcarrier is determined by the Mapping Matrix, which represents the complexity of MPA detection. Constellation Function Operator aims to design distinct codebooks for collision layers by incorporating several operators such as complex conjugate, phase rotation, and dimensional permutation [17]. In an SCMA encoder, the input bits are mapped to a K-dimensional sparse code-word selected from a predefine codebook of size M. K-dimensional complex code-words of the codebook are sparse vectors with N < K nonzero entries, and all code-words contain 0 in the same dimensions, as a result the codebook is sparse. The codebooks are constructed by a mapping from an N-dimensional complex constellation for the *j*th layer/user $\mathbb{g}_j$ with a mapping matrix $\mathbb{V}_j$. The constellation function $\mathbb{g}_j$ creates a constellation set $\mathbb{C}_j$ that contains M_j constellation alphabets of length N_j. The binary mapping matrix $\mathbb{V}_j \in \mathbb{B}^{K\times N}$ maps the N_j dimensional constellation points to SCMA code-words to form the code-word set X_j of the codebook $\boldsymbol{CB}_j$. Without loss of generality, we can assume that all the layers have the same constellation size and length, i.e, $M_j = M$, $N_j = N$, $\forall_j$. Multidimensional codebooks can be expressed for the *j*th user as [17]:

$$\boldsymbol{CB}_j = \mathbb{V}_j \Delta_j \mathbb{G}_{MC}, \text{ for } j = 1, 2, 3, \ldots, J. \tag{4.1}$$

where Δ_j refers to the constellation operator for *j*th user respectively and $\mathbb{G}_{MC}$ denotes the multi-dimensional mother constellation. The mapping matrix is chosen in such a way that each user only has active transmissions over a few fixed Physical Resource Elements (PRE). The distribution of PREs among users can be represent by a factor matrix $\boldsymbol{\mathcal{F}} = [\ f_1,\ \ f_2,\ \ f_3, \ldots,\ \ f_J]$, where $f_j = \text{diag}(\mathbb{V}_j \mathbb{V}_j^T)$. $\boldsymbol{\mathcal{F}}_{jk} = 1$ signifies that the user *j* has active transmission over the *k*th PRE. The factor matrix for an SCMA block having user $J = 6$ and orthogonal resource elements K = 4 is given as [16]:

$$\boldsymbol{\mathcal{F}}_{4\times 6} = \begin{bmatrix} 1 & 1 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 1 & 1 & 0 \\ 0 & 1 & 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 \end{bmatrix} \tag{4.2}$$

In $\boldsymbol{\mathcal{F}}_{4\times 6}$, each row corresponds to a PRE and each column corresponds to a user, respectively.

The binary mapping matrices for the six users are shown below.

$$\mathbb{V}_1 = \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 0 & 0 \\ 0 & 0 \end{bmatrix}, \quad \mathbb{V}_2 = \begin{bmatrix} 1 & 0 \\ 0 & 0 \\ 0 & 1 \\ 0 & 0 \end{bmatrix}, \quad \mathbb{V}_3 = \begin{bmatrix} 1 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 1 \end{bmatrix},$$

$$\mathbb{V}_4 = \begin{bmatrix} 0 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 0 \end{bmatrix}, \quad \mathbb{V}_5 = \begin{bmatrix} 0 & 0 \\ 1 & 0 \\ 0 & 0 \\ 0 & 1 \end{bmatrix}, \quad \mathbb{V}_6 = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 1 & 0 \\ 0 & 1 \end{bmatrix}$$

V1 indicates that data from user 1 are transmitted over the first and second PREs. Similarly, V2 indicates that data from user 2 are transmitted via the first and third PREs, and so on. Once the mapping matrices are determined, mother constellation $\mathbb{G}_{MC}$ and layer-specific operations, Δ_j are required. Unitary rotations can be applied to a mother constellation to increase power variation among different users, thereby reinforcing the "near-far effect" for reducing multiusers interference and increasing constellation shaping gain. Following the design of the mother constellation, layer-specific operations are used to generate multiple CBs for different users. Phase rotation, complex conjugate, layer power offset, and dimensional permutation are included for the further operations. In brief, for the jth user the resulting codebook contains M code-words, each code-word consists of K complex values from which only N are nonzero specified by the mapping matrix $\mathbb{V}_j$.

4.3.2 SCMA System Model and Multiplexing

A symbol synchronous uplink SCMA encoder includes J users communicate over K physical resource elements (PREs) and each encoding $log_2(M)$ bits to $\boldsymbol{C}$ where $M = 2^b$, b denoting the number of bits per code-word and $\boldsymbol{C} \in \mathbb{C}^k$ is a K dimensional complex codebook. Let C denotes N dimensional complex constellation point and an SCMA encoder can be redefined in mathematical expression as $F \equiv .\mathbb{g}$, where $\mathbb{V}$ is a binary mapping matrix and $\mathbb{V}_{ij} \in \{0,1\}$. The binary mapping matrix $\mathbb{V}$ maps the N dimensional constellation point to K dimensional SCMA code-word, which includes K−N all zero rows and hence, all the code-word in the codebook contain 0 in the same K−N dimensions. Eliminating all zero rows from matrix $\mathbb{V}$, the rest can be represented by an identity matrix $\boldsymbol{I}_N$ of size N. For an uplink SCMA system, J separate layers can be represented by $\boldsymbol{S}_j$ ($\mathbb{V}_j$, $\mathbb{g}_j$, M_j, N_j, K), j = 1,2,3,….., J. The constellation set $\mathbb{C}_j$ contains M_j alphabets of length N_j. The N_j dimensional constellation points are mapped by the mapping matrix $\mathbb{V}_j$ to SCMA code-word to form the code-word set X_j. For reducing the complexity of the expression, the size and length of the constellation across all layers are the same to be assumed, $M_j = M$, $N_j = N$, $\forall_j$. In short, an SCMA code can also be expressed by $\boldsymbol{S}$ ($[\mathbb{V}_j]_{j=1}^J$, $[\mathbb{g}_j]_{j=1}^J$, J, M, N, K). SCMA code-words are multiplexed through K shared orthogonal resources.

In the receiver terminal, the received signal $\mathcal{Y}$ after the synchronous layer multiplexing can be expressed as [15]:

$$\mathcal{Y} = \sum_{j=1}^{J} diag(\boldsymbol{h}_j)\boldsymbol{x}_j + \boldsymbol{n} \tag{4.3}$$

Since $\boldsymbol{x}_j = \mathbb{V}_j \mathbb{g}_j(\boldsymbol{b}_j)$, hence the received signal can also be expressed as [15]:

$$\mathcal{Y} = \sum_{j=1}^{J} diag(\boldsymbol{h}_j)\mathbb{V}_j \mathbb{g}_j(\boldsymbol{b}_j) + \boldsymbol{n}, \tag{4.4}$$

where $\boldsymbol{h}_j = \left(\boldsymbol{h}_{1j}, \dots \;, \boldsymbol{h}_{kj}\right)^T$ is the effective channel fading coefficient of layer j, $\boldsymbol{x}_j = \left(\boldsymbol{x}_{1j}, \dots \;, \boldsymbol{x}_{kj}\right)^T$ is the transmitted SCMA code-word of the layer j and $\boldsymbol{n}$ is the ambient noise vector, each element of which can be represented as complex Gaussian distribution $\mathcal{CN}\ (0,\sigma^2)$ where $\sigma^2 = N_o\boldsymbol{I}$, N_o is the normalized variance. Here, $\boldsymbol{h}_{kj}$ and $\boldsymbol{x}_{kj}$ denote the channel fading coefficient for the jth user at the kth PRE and the code-word element transmitted by the jth user on the kth PRE. In case all layers are transmitted from the same transmit point, all the channels to a target receiver are identical i.e. $\boldsymbol{h}_j = \boldsymbol{h}$, $\forall_j$ and so equation (4.3) can be reduce to [15]

$$\mathcal{Y} = \ diag\ (\boldsymbol{h}) \textstyle\sum_{j=1}^{J} \boldsymbol{x}_j + \boldsymbol{n} \tag{4.5}$$

By multiplexing J layers over K resources, the overloading factor of the code can be defined as λ = J/K. An SCMA system multiplexing shown in figure 4.2.

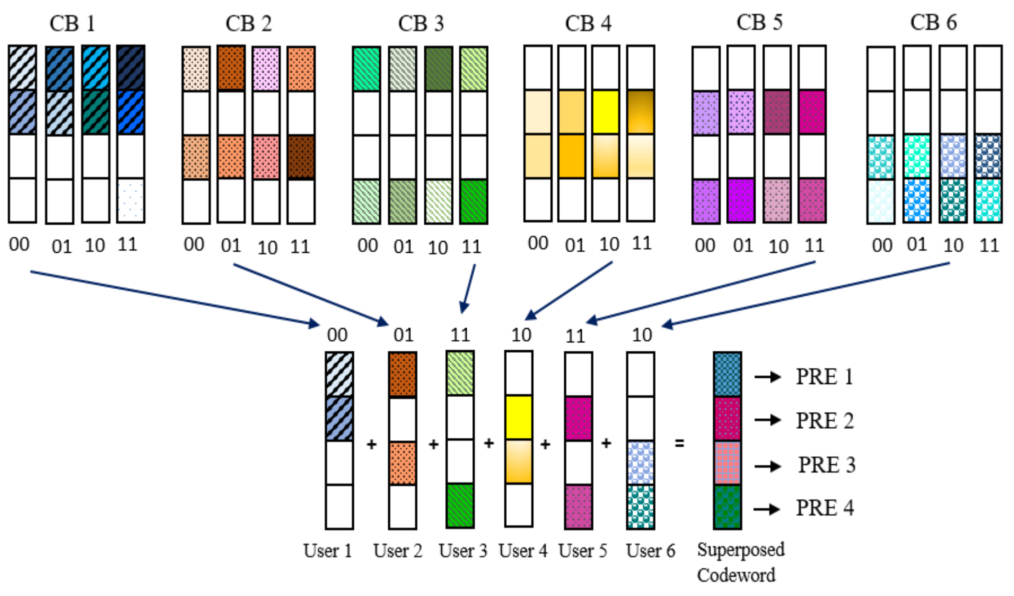

Figure 4. 2: A Demonstration of SCMA Multiplexing [13]

4.3.3 Factor Graph Representation

A factor graph can efficiently characterize the low density structure of SCMA code-words, which is similar to that for low density parity check (LDPC) codes. To signify the positions of zero (0) and nonzero (1) entries of the jth codebook a binary column vector f_j of length K is to be used and then a $K \times J$ dimensional sparse matrix $\boldsymbol{\mathcal{F}} = [\ f_1,\ \dots\ ,\ f_J\ ]$ is called the factor graph matrix. The columns of sparse matrix $\boldsymbol{\mathcal{F}}$ indicate the layers J and rows indicates the physical resources K. The mapping relation J users and K physical elements resources (PREs) can be expressed by a factor graph. The structure of SCMA code $\boldsymbol{\mathcal{S}}$ can be represented by a factor graph matrix defined as $\boldsymbol{\mathcal{F}} = (\ f_1,\ \dots\ ,\ f_J\ )$ and the $(k,\ j)$ th elements of the matrix denoted as $f_{k,j}$. If the *jth* elements of the *k-th* row is non-zero, the layer J and resource K are connected which means that when $f_{k,j} = 1$ there is an edge between layer J and resource K. The received signal at the resource K can mathematically expressed as [11]:

$$\mathcal{Y}_k = \sum_{j=1}^{J} \boldsymbol{h}_{kj} \boldsymbol{x}_{kj} + \boldsymbol{n}_{\boldsymbol{k}},\ k = 1,\ \dots ,\ \mathrm{K} \tag{4.6}$$

Since the code-words $\boldsymbol{x}_j{}'s$ are sparse, as a result only a few of them conflict over the resource K. The set of resources engaged by the layer J depends on the mapping matrix $\mathbb{V}_j$ and the set is determined by the index of the non-zero elements of the binary indicator vector $f_j = \mathrm{diag}\ (\ \mathbb{V}_j \mathbb{V}_j{}^T\ )$. The total number of layers contributing to the resources is determined by $\boldsymbol{d}_f = (d_{f1},\ \dots,\ d_{fk})^T = \sum_{j=1}^{J} f_j$. Consider the layer J as variable node (VN) and resource K as function node (FN) in the factor graph representation and the jth VN is connected to kth FN if and only if $f_{k,j} = 1$. The index set of VNs sharing to the kth FN, and the index set of FNs engaged by the jth VNs can be expressed respectively as follows [12]:

$$\varphi_k = \{\ j\ : 1\ \le j\ \le J,\ f_{k,j} = 1\} \tag{4.7}$$

$$\emptyset_j = \{\ k\ : 1\ \le k\ \le K,\ f_{k,j} = 1\ \} \tag{4.8}$$

For a regular factor graph matrix $|\ \varphi_1\ | = \cdots = |\ \varphi_k\ |$ and $|\ \emptyset_1\ | = \cdots = |\emptyset_j|$, and let $d_f = \varphi_k$ and $d_v = \emptyset_j$. For an SCMA transmission system with J = 6 layers and K= 4 PRE, the overloading factor λ = J/K = 1.5, the number of layer superimposing over one PRE, $d_f = 3$, and the number of non-zero elements in a column (from 4.3), $d_v = 2$ which means that each VN is connected to two FNs and each FN is connected to three VNs respectively. The corresponding factor graph is shown in figure 4.3.

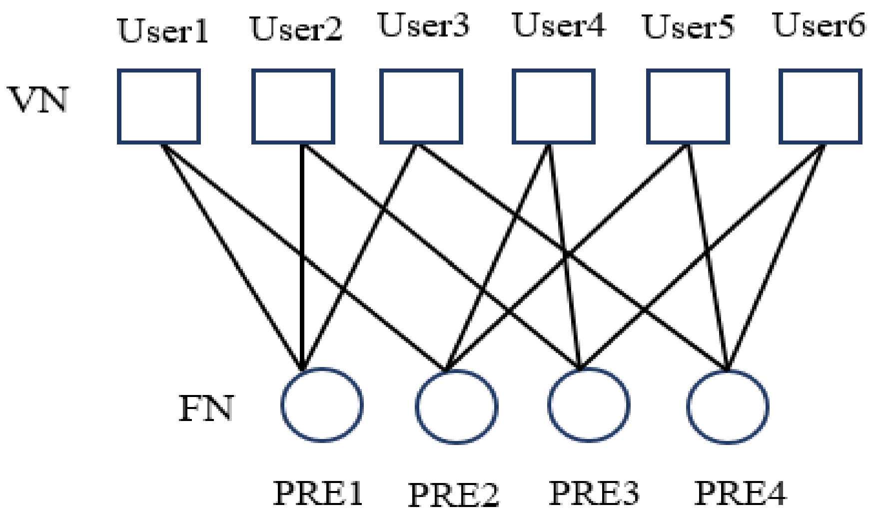

Figure 4. 3: Factor Graph Representation of an SCMA System [18]

4.4 SCMA Decoder

From the factor graph representation of an SCMA system, we can see that each user's information is transmitted by two PREs that is why the reception complexity is increased at the SCMA receiver; specially the system must simultaneously search for information in two places. In this section Sum Product Algorithm (SPA) is used to detect the symbols transmitted by each user. In sparse matrix $\boldsymbol{\mathcal{F}}_{4\times6}$ given in (4.2), there are $d_f = 3$ ones in each row and $d_v = 2$ ones in each column respectively. Every row corresponds to a PRE and every column corresponds to a user, respectively. In sparse matrix $\boldsymbol{\mathcal{F}}_{4\times6}$, the first column indicates first user and it has non-zero (1) values at the first and second rows which means that data of first user is transmitted on the first and second RREs, hence there is an edge between user 1 (VN) to PRE 1 (FN) and PRE 2 (FN) respectively. The second row of $\boldsymbol{\mathcal{F}}_{4\times6}$ indicates second PRE and it has ones at 1st, 4th and 5th position, which means that data of first, fourth and fifth user overlaps on second PRE and thus there are edges connecting the PRE 2 (FN) with user 1 (VN), user 4 (VN), user 5 (VN) respectively shown in figure 4.3. SCMA code-words detection and decoding are influenced by code design, channel performance, and noise. To reduce the interference between users based on the sparsity of code-words the MPA detector is used at the receiver [4]. This detector relies on the iterative exchange of messages between resource nodes and layer nodes, and a detailed description can be found in [4].

4.4.1 MAP Detection

Maximum a posteriori (MAP) is a decoding algorithm that iteratively updates the extrinsic information of variable nodes (VN) and function nodes (FN) along the edges in a factor graph. An optimal detector's goal is to minimize the probability of error ($\mathsf{P}(e)$) for the transmitted bit sequence $\boldsymbol{x}$, in another word to minimize the mismatch between transmitted bits $\boldsymbol{x}$ and estimated bits $\widetilde{\boldsymbol{x}}$ [7].

$$min\, \mathsf{P}(e) = min\, \mathsf{P}(\boldsymbol{x} \neq \widetilde{\boldsymbol{x}}) \tag{4.9}$$

For the channel coefficient $\boldsymbol{h}$ and the given received signal, error probability can be defined as [7]:

$$\mathsf{P}(e) = \int \mathsf{P}(e \mid \mathcal{Y})\, \boldsymbol{f}(\mathcal{Y}) d\mathcal{Y}, \tag{4.10}$$

where $\mathsf{P}(e \mid \mathcal{Y})$ denotes the error probability of given received signal and $\boldsymbol{f}(\mathcal{Y})$ denotes the probability density function (PDF) of $\mathcal{Y}$. The probability of desired signal $\boldsymbol{x}$ given received signal $\mathcal{Y}$ denoted as $\mathsf{P}(\boldsymbol{x} \mid \mathcal{Y})$. To minimize the probability of error, $\mathsf{P}(\boldsymbol{x} \mid \mathcal{Y})$ needs to be maximized due to (4.11) [7] and the detection scheme is called maximum a posteriori (MAP) detection.

$$\mathsf{P}(e) = 1 - \mathsf{P}(\boldsymbol{x} \mid \mathcal{Y}) \tag{4.11}$$

Given the received signal $\mathcal{Y}$ and the fading channel coefficient $\{\boldsymbol{h}_j\}_{j=1}^{J}$ the joint optimum MAP detection for multi-user code-word $\boldsymbol{x}$ and for the jth user's code-word $\boldsymbol{x}_j$ can be expressed as [8]:

$$\widetilde{\boldsymbol{x}} = arg \max_{\boldsymbol{x} \in (\times_{\boldsymbol{j=1}}^{\boldsymbol{J}})\{\boldsymbol{x}_j\}} \mathsf{P}(\boldsymbol{x} \mid \mathcal{Y}), \tag{4.12}$$

where $(\times_{\boldsymbol{j=1}}^{\boldsymbol{J}})\{\boldsymbol{x}_j\}$ **:** $\{\boldsymbol{x}_1\} \times \{\boldsymbol{x}_2\} \times \{\boldsymbol{x}_3\} \times \ldots \times \{\boldsymbol{x}_J\}$, which is the codebook for multi-users can be denoted as $\boldsymbol{CB}_j$ and $\{\boldsymbol{x}_j\}$ is the codebook for jth user [8].

$$\tilde{\boldsymbol{x}}_J = arg \max_{\boldsymbol{x}\in\{\boldsymbol{x}_j\}} \sum\nolimits_{\boldsymbol{x}\epsilon \boldsymbol{CB}_j} \quad \mathrm{P}(\boldsymbol{x} \mid \mathcal{Y}) \tag{4.13}$$

Because according to Bayes rule [7],

$$\mathrm{P}(\boldsymbol{x} \mid \mathcal{Y}) = \frac{\boldsymbol{f}\,(\mathcal{Y}|\boldsymbol{x})\mathrm{P}\,(x)}{\boldsymbol{f}\,(\mathcal{Y})} \propto \boldsymbol{f}\,(\mathcal{Y}|\boldsymbol{x})\mathrm{P}\,(\boldsymbol{x}), \tag{4.14}$$

where $\boldsymbol{f}\,(\mathcal{Y}|\boldsymbol{x})$ indicates the conditional pdf of $\mathcal{Y}$ given $\boldsymbol{x}$ and $\boldsymbol{f}\,(\mathcal{Y})$ indicates the pdf of $\mathcal{Y}$, respectively [8].

$$\mathrm{P}(\boldsymbol{x}) = \prod\nolimits_{j=1}^{J} \mathrm{P}(\boldsymbol{x}_j), \text{ and } \quad \mathrm{P}(\mathcal{Y}) = \boldsymbol{f}\,(\mathcal{Y}|\boldsymbol{x})\mathrm{P}\,(\boldsymbol{x})$$

By assuming the noise components over the K PREs are identically independently distributed, so

$$\boldsymbol{f}\,(\mathcal{Y}|\boldsymbol{x}) = \prod\nolimits_{k=1}^{K} \boldsymbol{f}(y_k|\boldsymbol{x}), \tag{4.15}$$

where $k = 1, \ldots, K$ denotes the PREs and y_k is the received signal at the *k*th PRE.

Therefore, the MAP decision for the *j*th user's code-word is given by [9]

$$\tilde{\boldsymbol{x}}_J = arg \max_{\boldsymbol{x}\in\{\boldsymbol{x}_j\}} \sum\nolimits_{\boldsymbol{x}\epsilon \boldsymbol{CB}_j} \quad \left(\mathrm{P}(\boldsymbol{x}) \prod\nolimits_{k=1}^{K} \boldsymbol{f}(y_k|\boldsymbol{x}) \right) \tag{4.16}$$

This scheme has marginalize product of functions (MPF) problem which can be easily solve by using low complexity message passing algorithm (MPA) with near optimal performance.

4.4.2 Message Passing Algorithm (MPA)

The message passing algorithm (MPA) is a method for performing inference from graphical models by passing belief messages between nodes. MPA calculates the marginal probability of different code-words using the sum-product algorithm (SPA). The code-word probability is calculated using Bayesian probability methods based on an initial probability within the codebook. For six users and four code-words in each codebook, it is assumed that each selected code-word has the same probability, and also assumed that all users transmit within the same data frame because there is no prior knowledge of the data to be transmitted. As a consequence, the initial probability of a user can be determined by selecting a code-word equal to 1 divided by the cardinality M of the code-word set in each user's codebook [18]. As a result, all code-words start with a probability of 1/4. MPA is a complex algorithm that works with joint probabilities and requires a significant amount of machine time to perform calculations.

4.4.3 Sum Product Algorithm (SPA)

In the sum-product algorithm (SPA) messages passing starts from leaf nodes. Without loss of generality, consider a factor graph having *J* variable nodes (users) and *K* function nodes (PREs) shown in figure 4.3 to explain the SPA method. This method consists two steps such as message passing from VNs to FNs and message passing from FNs to VNs. If a node has a degree (the number of edges connected to it) of q, it will remain idle until messages arrive on q-1 edges. Let $m_{j\to k}$ be the message transmitted from the *j* VN to the k FN. Similarly, let $m_{k\to j}$ be the message from the k FN to the j VN. Let, φ_k and $\emptyset_j$ are the set of nodes directly connected to *j* VN and *k* FN respectively and P_j be the set of transmitted symbol from *j* VN and $p_j \in P_j$.

- Message passing from *j* VN to *k* FN [18]:

$$m_{j\to k}(p_j) = \prod_{q\in\emptyset_j/\{k\}} m_{q\to j}(\, p_j), \tag{4.17}$$

where $q \in \emptyset_j/\{k\}$ denotes the FNs in $\emptyset_j$ except the *k*th FN. The message is normalized to ensure that the sum of all the probabilities is equal to 1.

$$m_{j\to k}(p_j) = \frac{\prod_{q\in\emptyset_j/\{k\}} m_{q\to j}(\, p_j)}{\sum_{p_j}\prod_{q\in\emptyset_j/\{k\}} m_{q\to j}(\, p_j)} \tag{4.18}$$

- Message passing from k FN to the *j* VN [18]:

$$m_{k\to j}(p_j) = \sum_{p_j}\left(\psi(\varphi_k) \prod_{q\in\varphi_k/\{j\}} m_{q\to k}(p_q\right), \tag{4.19}$$

where $\psi(\varphi_k)$ is the likelihood function associated with k FN and $q \in \varphi_k/\{j\}$ denotes all the VNs of φ_k except j VN, respectively. $m_{q\to k}(p_q)$ denotes the message from the q VN to the k FN corresponding to symbol p_q. Since the algorithm employs the sum and product operations, it is named as the sum-product algorithm.

4.4.4 Disadvantages of SCMA System

Even when a sparse signature sequence is used, the main disadvantage of SCMA is its high detection and decoding complexity. When a large size constellation and a large number of users are used, the detection and decoding complexity increases even more. As seen in [19], polar code can reach the capacity of a discrete binary-input memoryless channel (B-DMC). As a result, it has recently drawn a lot of attention. Polar code is chosen as the standard coding method for the control channel in support of the enhanced mobile broadband (eMBB) service, under 3GPP TR 38.802, due to its excellent error-correction capacity, particularly for short-length packet transfers. A variety of sophisticated decoding algorithms were developed in greater detail [20-24]. These polar decoders can generally be divided into two categories: a) The first category is based on the original successive cancellation (SC) decoders [21-23], such as successive cancellation stacking (SCS) decoder [22] and successive cancelation hybrid (SCH) decoder [21]. These decoders are able to perform admirably in terms of bit error rate (BER). They do, however, undergo serial processing, which results in a limited throughput of data processing. b) The second type, in contrast, is based on the BP algorithm [20], [24], [25], where soft information can be processed in parallel. As a result, a higher throughput of data processing is attained. The significant computational complexity of the BP decoder during the inner repetitions causes a substantial decoding latency, though. With the help of the accomplishments listed above, polar code is now a viable channel coding contender for the next-generation wireless communication system, even going up against the potent turbo code. Incorporating polar code into SCMA systems is thus desirable, and a significant performance boost is anticipated.

4.5 Polar Coded SCMA

The simultaneous design of polar coding and sparse code multiple access (SCMA), two fundamental technologies for 5G mobile communication, has a significant impact on how well the transmitter-receiver symmetric wireless communication system performs altogether [26]. In comparison to turbo code and low density parity check (LDPC) code, polar code, a common control channel coding method that allows enhanced mobile broadband, has outstanding error correction performance and lower coding and decoding complexity [19]. In order to provide a higher quality of service in real applications, SCMA must be combined with channel coding technology, which includes turbo code, LDPC code, and polar code.

Through the use of channel coding, such as turbo and LDPC codes, SCMA systems' performance can be enhanced. Turbo-coded SCMA systems' bit error probability (BER) performance was examined in [27].

Polar codes are what is referred to as channel coding technology, which refers to codes used for detecting and correcting errors caused by noise and interference in digital communication systems, in order to make them function properly. Polar codes are unique in that they are the world's first channel coding scheme that has been theoretically proven to reach Shannon's limit. In practice, this means increased computational power, memory, energy consumption, and latency. Polar was chosen as one of the channel codes for the upcoming 5G mobile communication standard. PCs are based on the channel polarization method, making them the first capacity-achieving codes that can be decoded sequentially. Furthermore, thanks to recursive techniques, the encoding and decoding operations can be performed with low complexity [28].

Polar codes are the first channel coding scheme to push us up against Shannon's limit, or the maximum rate at which data can be sent with zero error at a given bandwidth. Although polar code implementations are simpler and more adaptable than turbo code implementations for relatively low throughput channels, according to Marshall, polar code market maturity is lower than that of turbo code and polar code implementations are more difficult for higher throughput channels

[29]. Arikan has put out a plan for decoding based on the Successive Cancellation (SC) decoding algorithm. Nevertheless, SC's performance is constrained when compared to Turbo code and LDPC code [30-32]. As a result, a number of high-performance decoding algorithms have been presented, with numerous advancements based on SC decoding. It has been demonstrated that these algorithms, including the Sequence List SC decoding (SCL), belief propagation (BP) decoding, stack SC decoding (SSC), cyclic redundancy check assisted SCL decoding (CRC-SCL), and soft cancellation (SCAN) decoding algorithms, outperform Turbo codes and LDPC codes [33, 34]. Recent works [35] and [36] suggest a joint iterative detector and decoder for polar coded SCMA systems, where the polar decoders are based on the BP and SCAN algorithms, respectively.

4.5.1 Block Diagram of Polar coded SCMA System

We take into account a Polar-coded SCMA system with J users dispersed over K resources using an AWGN channel (additive white Gaussian noise), as shown in figure 4.4. Since J exceeds K, the ratio J:K is known as the overloading factor. For every user j, its I information bits k_j = $\{k_{j,1}, k_{j,2}, \ldots, k_{j,I}\}$ are encoded into polar codes p_j = $\{p_{j,1}, p_{j,2}, \ldots, p_{j,N}\}$. In order to minimize system interference caused on by burst errors, the polar codes P = $\{p_1, p_2, \ldots p_j\}$ are interleaved into $\{d_1, d_2, \ldots, d_j\}$ and then input to the SCMA encoder. Every Q bits set $\{d_{j,1}, d_{j,2}, \ldots, d_{j,Q}\}$ is mapped a M dimension code-word of the SCMA codebook according to the mapping relationship:

$\{d_{j,1}, d_{j,2}, \ldots, d_{j,Q}\} \rightarrow \{x_{j,1}, x_{j,2}, \ldots, x_{j,M}\}$, Q= log_2M, $x_{j,m}$ € C, and then transmitted to the channel. At the receiver, interleaver and de-interleaver are added between the SCMA detector and polar decoder for joint detection and decoding.

A SCMA factor matrix with j=6 and k = 4 can be denoted by [12]:

$$F = \begin{bmatrix} 0 & 1 & 1 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 & 0 & 1 \\ 0 & 1 & 0 & 1 & 0 & 1 \\ 1 & 0 & 0 & 1 & 1 & 0 \end{bmatrix} \tag{4.20}$$

The channel gain matrix for an uplink Polar coded-SCMA system is expressed as [25]:

$$H_j^l = \begin{bmatrix} h_{1,j}^l & 0 & 0 & 0 \\ 0 & h_{2,j}^l & 0 & 0 \\ 0 & 0 & \cdots & 0 \\ 0 & 0 & 0 & h_{k,j}^l \end{bmatrix} = \text{diag}\ \{ h_{1,j}^l, h_{2,j}^l, \ldots\ldots, h_{k,j}^l \} \tag{4.21}$$

Where $h_{k,j}^l$ denotes the channel gain of the l-th transmitted signal between resource k and user j.

Assuming that all users are synchronized in time, the l-th received signal is the superposition of all user signals, which, can be denoted as [29]:

$$y^l = \sum_{j=1}^{J} H_j^l\, x_j^l + w^l \tag{4.22}$$

Where $1 \leq l \leq L = N/Q$, $y^l = [y_1^l, y_2^l \ldots\ldots y_M^l]^T$. $x_j^l = [x_{j,1}^l, x_{j,2}^l \ldots\ldots x_{j,M}^l]^T$ is the l-th SCMA codes of user j.$w^l = [w_1^l, w_2^l \ldots\ldots w_M^l]^T$ represents the additive Gaussian noise vector in the channel and $w^l \approx$ cN $(0,\partial^2)$. Architecture of polar coded SCMA is shown in figure 4.4.

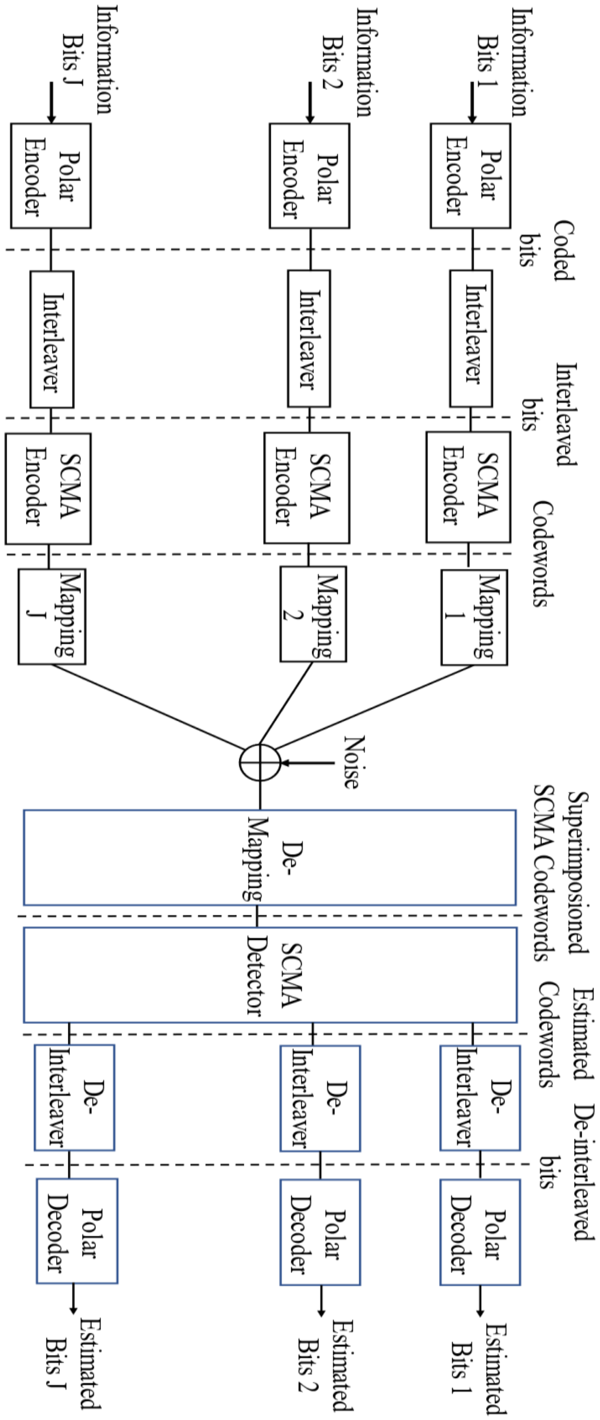

Figure 4. 4: Architecture of Polar coded SCMA System [30]

4.5.2 Disadvantages of Polar coded SCMA

Polar coding employs SCD (Successive Cancellation Decoder) technology, which performs poorly in comparison to LDPC and turbo coding techniques. They provide superior performance with advanced decoders at a higher cost than LDPC (at finite N). Low density parity check (LDPC) code is a promising technology in 5G New Radio communications. To ensure that the transmitted data is revived with minimal errors, the LDPC codes are used as the channel coding. The Successive Interference Cancellation (SIC) decoding algorithm in the LDPC-coded scheme loses the information of the minimum Euclidean distance of other code-words, resulting in better BER performance that violates the principles of increased code length and decreased code rate, while the coding scheme can also improve BER performance [37].

4.6 The Low Density Parity Check (LDPC) Coded SCMA System

The low density parity check (LDPC) code is an efficient channel coding scheme that allows transmission errors to be corrected. LDPC codes are extremely efficient because they provide a practical implementation that approaches the Shannon channel capacity of reliable transmission. The Shannon channel capacity rule states that a code with a code rate close to the capacity number causes the error to decrease to zero when decoding with the maximum likelihood decoder as the block length increases. This condition can be achieved by employing random linear block codes encoded as polynomials of time. However, as we increase the block length for error approaching zero, we run into the issue of complex computation algorithms for encoding and decoding, which eventually leads to a speed compromise [38]. So, in this case, LDPC code achieves the successful implementation of LDPC code at Shannon limit with long block lengths, as well as the additional benefits of less complex algorithms, greater speed, and accuracy.

Linear Block Code combines parity bits and message bits to form a code-word. Parity bits in transmitted code-words over a noisy channel assist us at the receiver side by detecting, correcting, and locating errors using decoding algorithms. This Linear code-word is represented by the (n, k) code-word, where n represents the encoded code block length and k represents the message bit. The code rate is defined as the number of message bits divided by the number of transmitted bits (k / n). As the code rate decreases, or the number of transmitted encoded bits increases, as a result message security or protection also increases. However, as the code rate decreases, so does the bandwidth, and the cost per bit rises as the total number of transmitted bits rises. In LDPC codes, the generator matrix is determined only after generating a sparse parity check matrix. “Sparse” means the number of nor zero elements (1s) is very less then the number of zero elements (0s) in the matrix. A sparse parity check matrix is shown in figure 4.5.

$$\boldsymbol{\mathcal{H}} = \begin{bmatrix} 0 & 1 & 0 & 1 & 1 & 0 & 0 & 1 \\ 1 & 1 & 1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 1 & 1 & 1 \\ 1 & 0 & 0 & 1 & 1 & 0 & 1 & 0 \end{bmatrix}$$

There are three parameters (n, w_c, w_r) to define the matrix where n indicates the length of the block code, w_c refers the number of ones in each columns and w_r refers the number of ones in each rows. Each column of matrix $\boldsymbol{\mathcal{H}}$ represents variable nodes (VNs) and each row of matrix $\boldsymbol{\mathcal{H}}$ represents a check node (CNs). Check nodes and Variable nodes indicate the set of parity check conditions and the elements of the code word respectively and in the matrix 1s means there is an edge between the check nodes and variable nodes.

4.6.1 The System Model

Consider a LDPC coded SCMA uplink multiple access system with *J* users over *K* shared orthogonal resources (PREs), and signalling through rayleigh fading channel with additive white Gaussian noise (AWGN) as shown in figure 4.6. In the non-orthogonal method, *J* can be greater than *K* and the overloading factor ratio λ is defined as *J/K*. In the system model, $\mathbb{B} = [\ b^1, b^2, b^3, \dots,\ b^j$ represent as the LDPC coded message bits transmitted in *J* uplink users. $\boldsymbol{x}^j = [\boldsymbol{x}_1^j, \dots \dots \boldsymbol{x}_K^j]^T$ defines the mapped complex symbol of the *j*th user and $\boldsymbol{x}_k^j$ defines the mapped symbol of *j*th user transmitted over *k*th PRE. For each user *j*, where *j* = 1, 2, …., *J* , at first input data bits

$\{a^{j}_{m_0} | \, m_0 = 1, 2, \dots, m\}$ are encoded into $\{b^{j}_{n_0} | \, n_0 = 1,2,3, \dots, n\}$ by an LDPC encoder with code rate (k / n). To reduce error bursts and maximize diversity gain, the coded bits are permuted by an interleaver μ_j. Each $log_2(M)$ interleaved coded bits $\{b^{j}_{n^{\mu}} | n^{\pi} = 1, 2, 3, \dots, \; log_2(M)\}$ is combined together and then mapped by SCMA mapper F into a K dimensional complex symbol vector as follows:

F: $\mathbb{B}^{log_2(M)} \rightarrow \mathcal{X}$, $\quad \boldsymbol{x} = F(\boldsymbol{b})$ where $\mathcal{X} \in \mathbb{C}^K$ with cardinality $|\mathcal{X}| = M$.

The whole SCMA encoding process is described in section 4.3. The system model of LDPC code SCMA is shown in figure 4.5.

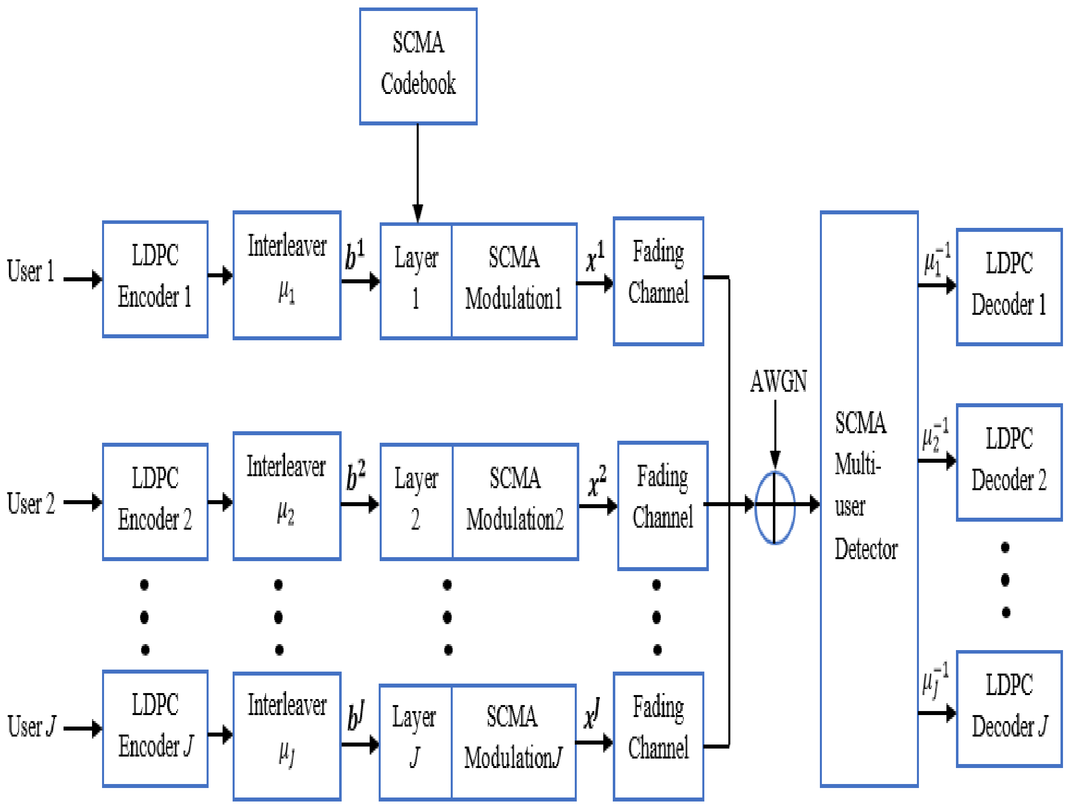

Figure 4. 5: System Model of LDPC coded SCMA

4.6.2 LDPC Encoding

An encoding algorithm for a binary linear code with dimension k and block length n is one that generates a code-word from k original bits $c_1, c_2, \ldots, c_k$. LDPC codes are given as the null space of a sparse matrix, rather than as the space generated by the rows of that matrix. In the encoding process of LDPC codes, two main functions are the construction of sparse parity check matrix and the generation of code-word. Sparsity of the parity check matrix indicates that each symbol nodes made very few connections to the check nodes in the tanner graph. By applying Gauss Jordan elimination method on the parity matrix $\boldsymbol{\mathcal{H}}$, generator matrix $\mathbb{G}$ can be determined. Often generator matrix is not sparse which leads to the complexity in the encoding process and the efficiency of encoding is quadratic with block length. The generator matrix is found by performing row permutations, modulo-2 operations on any two rows and some column permutations. So, the form of parity matrix $\boldsymbol{\mathcal{H}} = [\, A\, I_k]$, where A is the (n-k)×k binary matrix and I_k is the k dimensional identity matrix. Then the generator matrix is $\mathbb{G} = [\, I_k A^T]$. And then by multiplying the message bit stream with the generator matrix will get us a code-word of n bits.

$$\mathrm{C} = m \times \mathbb{G}$$

The tanner graph of sparse matrix in figure 4.5 is shown in figure 4.7.

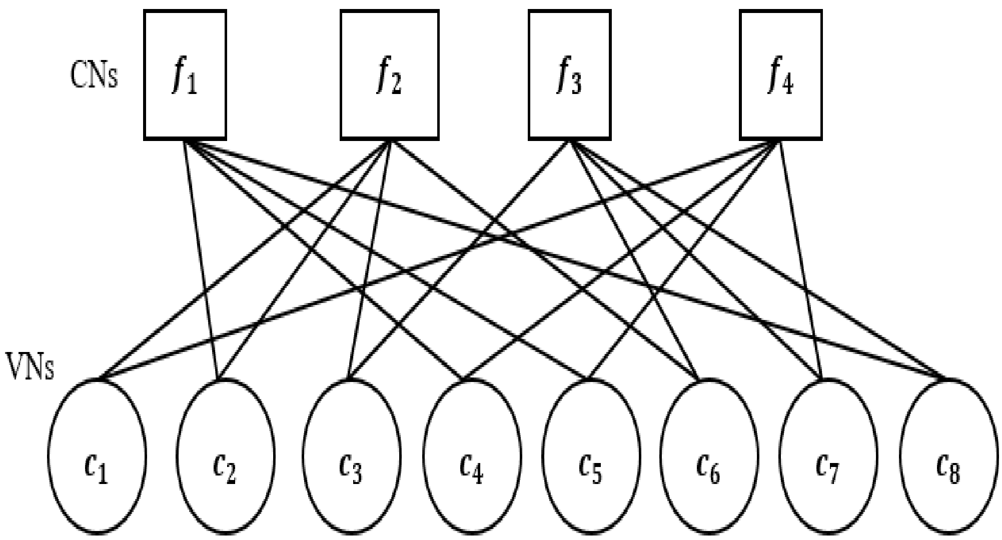

Figure 4. 6: Graphical Representation of Sparse Parity Matrix [38]

4.6.3 LDPC Decoding with SCMA Detection

The decoding process of LDPC codes is based on an iteration scheme in the Tanner graph between variable nodes (VNs) and check nodes (CNs). A message passing algorithm is a decoding scheme of LDPC codes that transmits messages forward and backward between variable nodes and check nodes. There are two types of message passing algorithms such as a hard decision decoding based on the bit flipping algorithm and a soft decision decoding based on the belief propagation algorithm. The sum-product algorithm is a soft decision type message passing algorithm.

4.6.4 MAP Based SCMA Detection:

The SCMA multiuser detection is implemented by using MAP based MP (message passing) detection scheme based on factor graph [29]. The symbol log likelihood ratio (LLR) is expressed as [39]:

$$L(\boldsymbol{x}) = lo\ g\left(\frac{P(x)}{P(\breve{x})}\right), \tag{4.23}$$

where $P(\boldsymbol{x})$ is the probability of symbol $\boldsymbol{x} \in \mathbb{C}$ and $\breve{\boldsymbol{x}}$ denotes a fixed reference symbol for which all labelling bits of $\breve{\boldsymbol{x}}$ are nonzero (1). Let $LV_{j\to k}$ and $LU_{k\to j}$ denote the symbol LLR from user node *j* to resource node *k* and the symbol LLR from resource node *k* to user node *j*, respectively. In the *t*-th SCMA iteration, denoted as $LV_{j\to k}^{t}$ and $LU_{k\to j}^{t}$ respectively. L_j^A denotes a priori symbol LLR for user node *j*, δj and δk denote the set of resource nodes connected to user node and the set of user node connected to resource node respectively. At the starting of each SCMA iteration a priori information for all user nodes is calculated based on the LLR values returned by the decoder. Each user node's soft information is passed to the adjacent resource nodes. Each resource node performs MAP detection using soft information from neighboring user nodes and returns the updated soft information to each neighboring user node. The detector outputs the final decision for all users after completing the desired number of iterations.

User node j receives the information $LU_{k\prime\to j}^{t-1}$ from each neighboring resource node *k'* and calculates $LV_{j\to k}^{t}$ as [39]:

$$LV_{j\to k}^{t} = L_j^A + \sum_{k\prime\in\delta j\backslash k} LU_{k\prime\to j}^{t-1} \tag{4.24}$$

Resource node k computes $LU_{k\to j}^{t}$ for each neighboring variable node j as [39]:

$$LU_{k\to j}^{t} = log\frac{\sum_{\substack{x_{k,j\prime}\in\mathbb{C} \\ j\prime\in\delta k\backslash j}} \exp[f_k(\boldsymbol{x}_{k,j})+\sum_{j\prime\in\delta k\backslash j} LV_{j\prime\to k}^{t}]}{\sum_{\substack{x_{k,j\prime}\in\mathbb{C} \\ j\prime\in\delta k\backslash j}} \exp[f_k(\breve{\boldsymbol{x}}_{k,j})+\sum_{j\prime\in\delta k\backslash j} LV_{j\prime\to k}^{t}]}, \tag{4.25}$$

where, $$f_k(\boldsymbol{x}_{k,j}) = \frac{1}{2\sigma^2}||\mathcal{Y}_k - h_{k,j}\boldsymbol{x}_{k,j} - \sum_{j'\in\delta k\backslash j} h_{k,j'}\boldsymbol{x}_{k,j'}||^2, \tag{4.26}$$

where σ^2 is the noise variance and $\breve{\boldsymbol{x}}_j$ is the fixed reference symbol for which all labelling bits of $\breve{\boldsymbol{x}}_j$ are non-zero (1). After the final iteration SCMA detector outputs a posteriori symbol LLR for each user j as [40]:

$$LV_j^q = L_j^A + \sum_{k\prime\in\delta j} LU_{k\prime\to j}^{T}, \tag{4.27}$$

where T is the number of SCMA iterations. In order to forward the soft information to the corresponding LDPC decoder, bit LLR values $L_{R,j}^{q,d}$ are calculated from the symbol LLR values as [40]:

$$L_{R,j}^{q,d} = log\frac{\sum_{x_j\in\mathbb{C}_d^0} \exp[LV_j^q]}{\sum_{x_j\in\mathbb{C}_d^1} \exp[LV_j^q]}, \tag{4.28}$$

where $\mathbb{C}_d^t$ consists of elements $\boldsymbol{x}_j$ in $\mathbb{C}$ for which the d-th labelling bit of $\boldsymbol{x}_j$ is t, where t = 0 and 1.

4.6.5 LDPC Decoding

LDPC is a sparse linear block code that can be represented as bipartite factor graph with variable nodes and check nodes. Considering the complexity of implementation, LDPC decoders typically use the MP algorithm with LLRs to reduce multiplication and avoid normalization. During each iteration, belief information is exchanged between variable nodes and check nodes based on the parity check matrix. Let $L_{1,j}^{q,d}(a_i)$ is the LLR of the *i*-th bit of user *j* input to decoder expressed as [40]:

$$L_{1,j}^{q,d}(a_i) = \log \frac{P(a_i=0|\mathcal{Y})}{P(a_i=1|\mathcal{Y})} \tag{4.29}$$

Then the LDPC decoder output is,

$$L_{2,j}^{q}(a_i) = L_{1,j}^{q,d}(a_i) + \sum_{s\in\delta i} L_{j,s\to i}, \tag{4.30}$$

where δi refers the set of parity check functions of *i-th* variable and $L_{j,s\to i}$ is the belief message passed from check node s to variable node i in the last iteration. $\sum_{s\in\delta i} L_{j,s\to i}$ represents the LDPC intrinsic information $L_{2,j}^{q}(a_i)$ based on LDPC structure. Thus, the LDPC decoder output can also be divided to prior information part and intrinsic information part.

Note that in (4.30) subscript '1' and '2' is used to refer the information generated by SCMA detector and LDPC decoder respectively.

4.6.6 Synthesis of SCMA detection and LDPC Decoding

The output of SCMA decoder provide the symbol LLR shown in (4.27) and LDPC decoder requires the bit LLR as an input. To synthesis the SCMA detector and LDPC decoder a transformation needs to be performed between symbol LLRs and bit LLRs. Using (4.28) the transformation is performed. Let N_T and N_S is the outer iteration number of SCMA detector and LDPC decoder respectively. In the synthesis scheme there are two inner stages besides outer iterations. the inner stages of an SCMA detection stage and LDPC decoding stage are connected by a module containing LLR converters, interleavers and deinterleavers. During every outer iterations the symbol LLRs $\{L_{1,j}^{q,d}(\boldsymbol{x}_j)\}$ of SCMA detector are transformed to bit LLR $\{L_{1,j}^{q}(a_i)\}$, input of the LDPC decoder. For the better performance the outputs of SCMA detector are fed into the deinterleaver to get $\{L_{1,j}^{q,d}(a_i)\}$ which is used as prior information LDPC decoder. Then finally we get the LDPC decoder output from which by calculating bit error rate (BER) the performance of the system is analysed.

4.7 Conclusion

Next generation wireless communication system requires high speed, low complexity, higher channel capacity to provide services among large number of subscriber simultaneously and to support a diverse set of vertical industries, including e-health, smart homes/cities, connected autonomous vehicles, and future factories. For the sake of the betterment of the performance of the 5G communication orthogonal multiple access (OMA) and non-orthogonal multiple access (NOMA) techniques are used. Now a days non-orthogonal multiple access (NOMA) is one of the key enabling technologies for the physical layer of 5G systems, which can not only provide higher spectral efficiencies but also support a greater number of connected subscribers than existing systems. In NOMA, SCMA system combines the advantages of low receiver complexity and improves the performances. But the main disadvantage of SCMA is its high detection and decoding complexity which can be overcome by using polar coded SCMA system. Polar code is a common control channel coding that has outstanding error correction performance and lower encoding and decoding complexity. Polar coding employs SCD (Successive Cancellation Decoder) technology, which performs poorly in comparison to LDPC and turbo coding techniques. Low density parity check (LDPC) code is a promising technology in 5G New Radio communications which provides a practical implementation that approaches the Shannon channel capacity of reliable transmission, as well as the additional benefits of less complex algorithms, greater speed, and accuracy. A system model is approached by combining LDPC code and SCMA system. The performance analysis of the LDPC coded SCMA and comparison with different types of multiple access techniques are discussed in the chapter 5.

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Chapter 5

Results and Discussion

In this chapter, we have described and also compared the performance between sparse code multiple access, polar coded sparse code multiple access (Polar coded SCMA) and low- density parity check coded sparse code multiple access. We have also shown the performance comparison of our proposed LDPC code SCMA scheme with SCMA and Polar coded SCMA. We have also discussed the performance comparison of LDPC-coded SCMA with other multiple access such as OFDM, OFDMA, and MC-CDMA.

5.1 Performance of Different Multiple Access Scheme

5.1.1 Bit Error Rate (BER) of OFDM

The simulation result of orthogonal frequency domain multiplexing (OFDM)

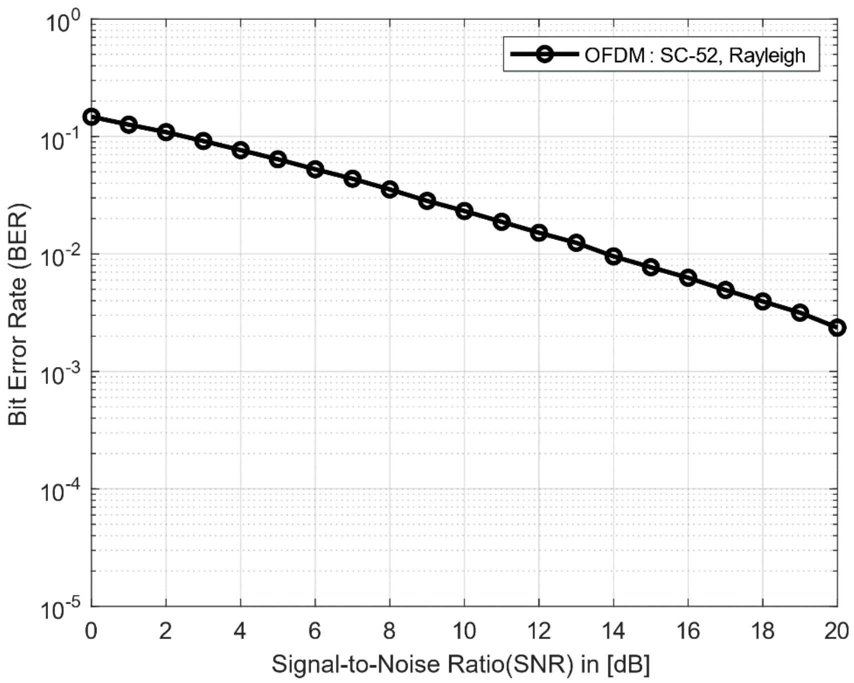

Figure 5. 1: SNR vs BER performance of OFDM.

Here, number of subcarriers = 52, number of symbols = 10^4, FFT size = 64.

Figure 5.1 shows the BER performance of orthogonal frequency division multiplexing (OFDM). As the figure depicts that regarding OFDM, the curve starts approximately from BER = 1×10^{-1} and SNR = 0 dB and reaches approximately at BER = 2.5×10^{-3} and SNR = 20 dB.

5.1.2 OFDM vs OFDMA

Orthogonal frequency division multiplexing is a popular multicarrier technology in communication networks. Multiplexing is stable against multipath fading and has a low level of complexity. The results of OFDM and OFDMA simulation are,

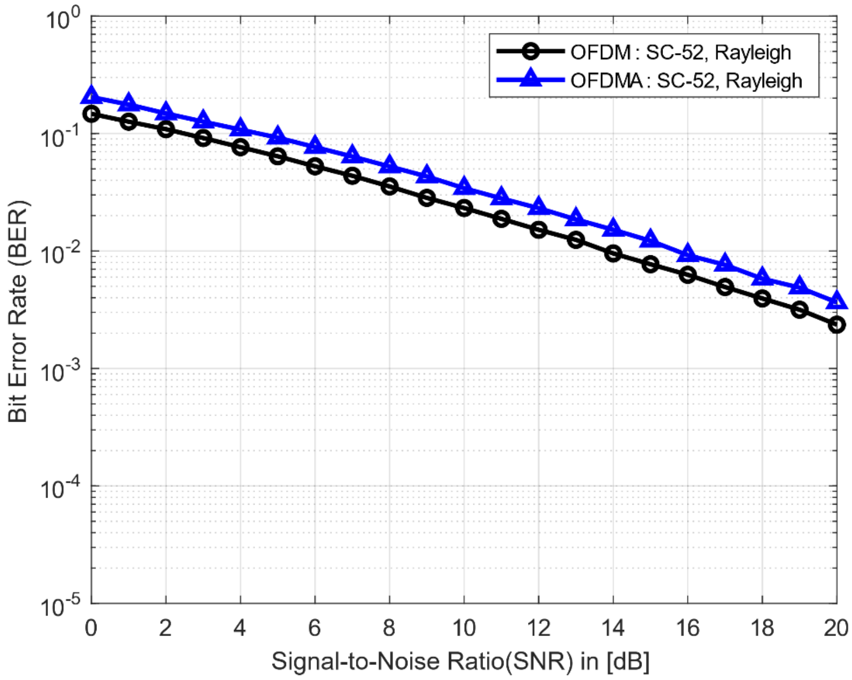

Figure 5. 2: BER performance of OFDM and OFDMA.

Here, number of subcarriers = 52, number of symbols = 10^4, FFT size = 64.

Figure 5.2 shows the BER performance of orthogonal frequency division multiplexing (OFDM) and orthogonal frequency division multiple access (OFDMA). As the figure depicts that regarding OFDM, the curve starts approximately from BER = 1×10^{-1} and SNR = 0 dB and reaches approximately at BER = 2.5×10^{-3} and SNR = 20 dB and in terms of OFDMA, the curve starts approximately at BER = 0.5×10^{-1} and SNR = 0 dB and reaches approximately BER = 1×10^{-3} and SNR = 20dB.

5.1.3 Performance of MC-CDMA over Rayleigh Channel

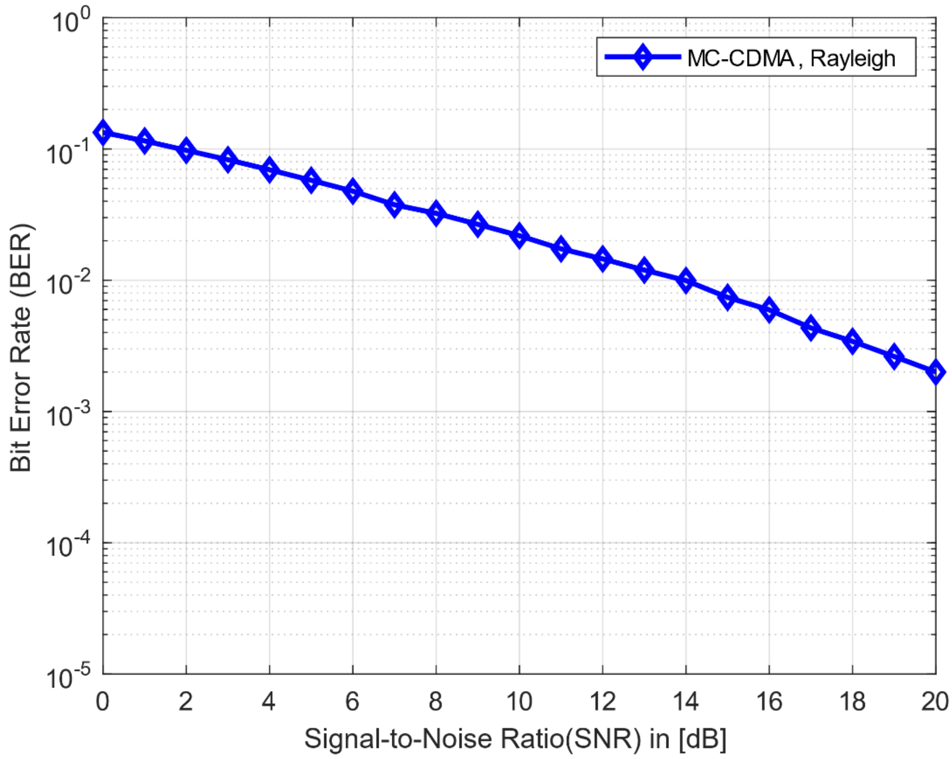

Figure 5. 3: SNR vs BER performance of MC-CDMA

Figure 5.3 shows the BER performance of multi carrier code division multiple access (MC-CDMA). As the figure depicts that regarding multi carrier code division multiple access (MC-CDMA), the curve starts approximately from BER = 0.5×10^{-1} and SNR = 0 dB and reaches approximately at BER = 1×10^{-3} and SNR = 20 dB.

5.1.4 Comparison of OFDM, OFDMA and MC-CDMA

Combining OFDM and CDMA leads in MC-CDMA, which is notable for its high ghastly proficiency, multiple entrance ability, strength due to recurrence-specific channels, simple one-tap adjustment, thin band impedance dismissal, and high adaptability [1]. The results of OFDM, OFDMA and MC-CDMA simulation are,

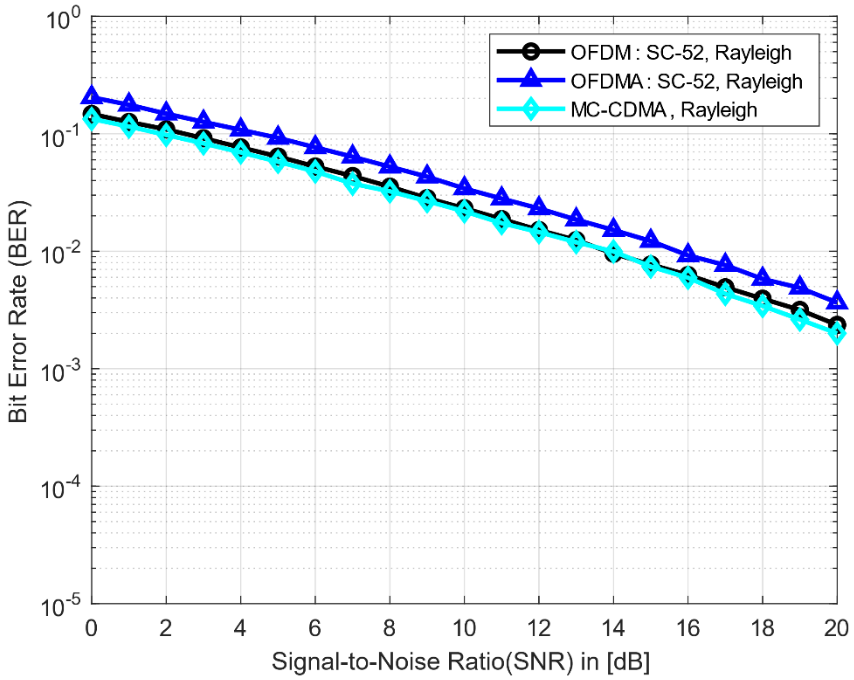

Figure 5. 4: BER Performance of OFDM, OFDMA and MC-CDMA.

Here, number of subcarriers = 52, number of symbols = 10^4, FFT size = 64.

Figure 5.4 shows the BER performance of orthogonal frequency division multiplexing (OFDM), orthogonal frequency division multiple access (OFDMA) and multi carrier code division multiple access (MC-CDMA). As the figure depicts that regarding OFDM, the curve starts approximately from BER = 1×10^{-1} and SNR = 0 dB and reaches approximately at BER = $2.5{\times}10^{-3}$ and SNR = 20 dB and in terms of OFDMA, the curve starts approximately at BER = $0.5{\times}10^{-1}$ and SNR = 0 dB and reaches approximately BER = 1×10^{-3} and SNR = 20dB. On the other hand, As the figure depicts that regarding multi carrier code division multiple access (MC-CDMA), the curve starts approximately from BER = 0.5×10^{-1} and SNR = 0 dB and reaches approximately at BER = $1{\times}10^{-3}$ and SNR = 20 dB.

5.2 Performance of Sparse Code Multiple Access Schemes

5.2.1 Performance of SCMA

Better coverage due to spreading gain, Affordable low multi-user joint detection complexity and Users occupy the same resource blocks in a low density way are the most important advantages of SCMA. For faster, more reliable, and more efficient massive access, 6G supports massively distributed access systems with sparse code multiple access.

The simulation result of SCMA is shown in figure 5.5.

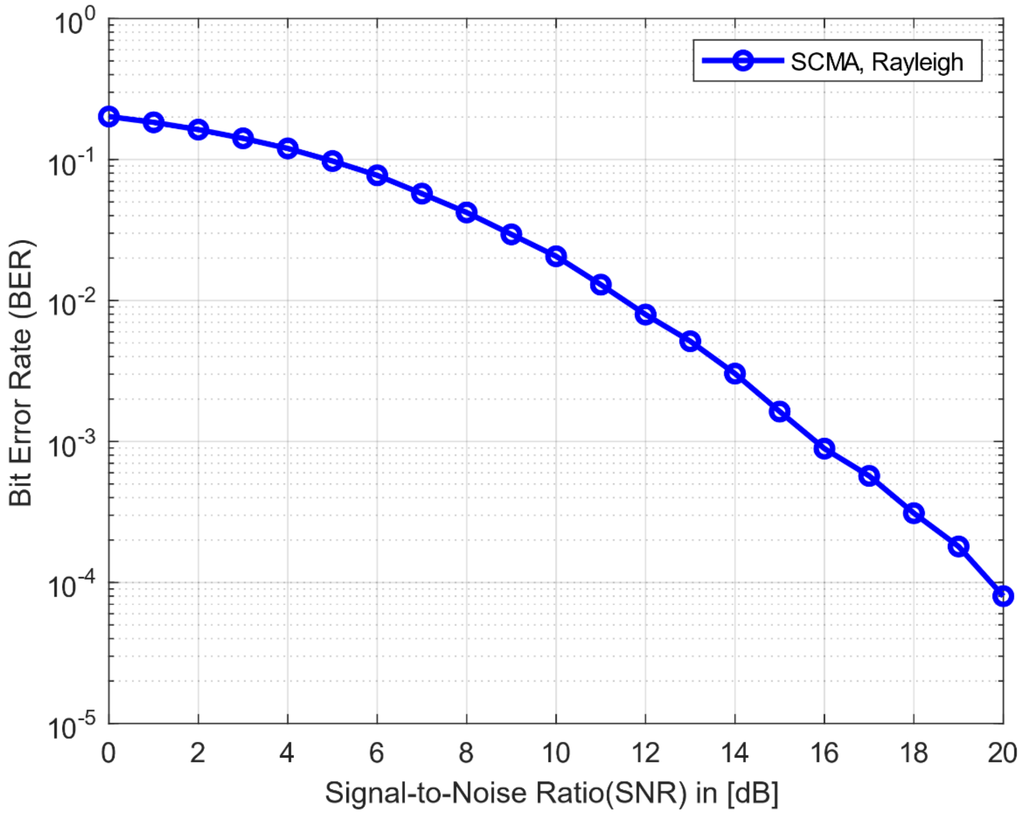

Figure 5. 5: SNR vs BER performance of SCMA.

Here, maximum number of bits = 10^5 , number of iteration = 10 , maximum number of error = 10^5

Figure 5.5 shows the BER performance of sparse code multiple access (SCMA). As the figure depicts that regarding SCMA, the simulation curve starts approximately from BER = 1×10^{-1} and SNR = 0 dB and reaches approximately at BER = 7×10^{-5} and SNR is after 20 dB.

5.2.2 Performance of Polar coded SCMA

Polar coded Sparse Code Multiple Access is more efficient than traditional SCMA [2]. The result of Polar coded SCMA simulation is represented in figure 5.6.

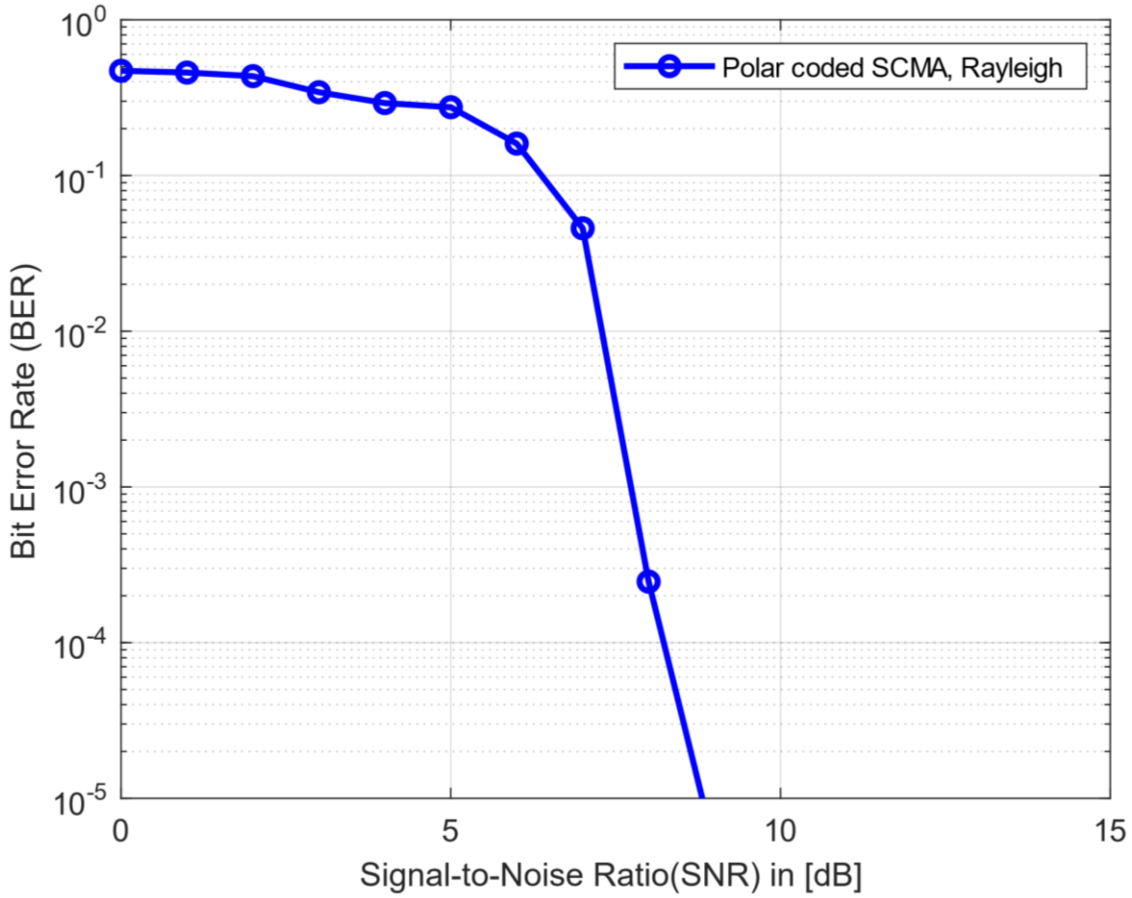

Figure 5. 6: SNR vs BER performance of Polar coded SCMA

Here, maximum number of bits = 10^7, minimum number of bits = 50000, minimum number of errors = 50.

Figure 5.6 shows the BER performance of Polar coded SCMA. As the figure depicts that regarding Polar coded SCMA, the curve starts approximately from BER = 4×10^{-1} and SNR = 0 dB and reaches approximately at BER = 10^{-5} and SNR = 9 dB.

5.2.3 Performance comparison of SCMA and Polar Coded SCMA

After reading many research papers, we found that Polar coded SCMA performs much better than SCMA. The results of SCMA and Polar coded SCMA simulation are as follows:

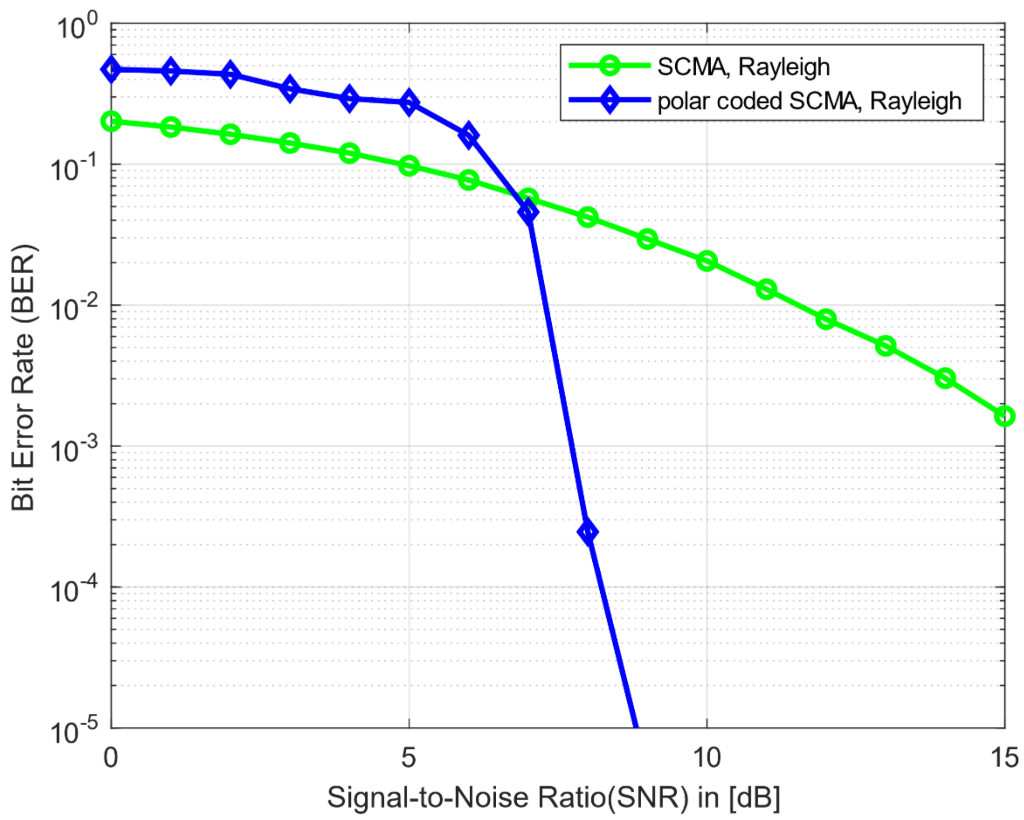

Figure 5. 7: SNR vs BER performance of Polar coded SCMA

Figure 5.7 shows the BER performance of sparse code multiple access (SCMA) and polar coded sparse code multiple access (PC-SCMA). As the figure depicts that regarding SCMA, the curve starts approximately from BER = 1×10^{-1} and SNR = 0 dB and reaches approximately BER = 0.5×10^{-3} at SNR = 15 dB. On the other hand, as the figure also depicts that regarding polar coded SCMA, the curve starts approximately from BER = 4×10^{-1} and SNR = 0 dB and reaches approximately at BER = 10^{-5} when SNR = 9 dB. Due to the lower BER, We can clearly see that Polar coded SCMA is better than SCMA.

5.2.4 Performance of LDPC coded SCMA

Low density parity check coded sparse code multiple access is a capacity control code which give good bit error rate (BER) performance. The computer simulation result of LDPC coded SCMA is given in figure 5.8.

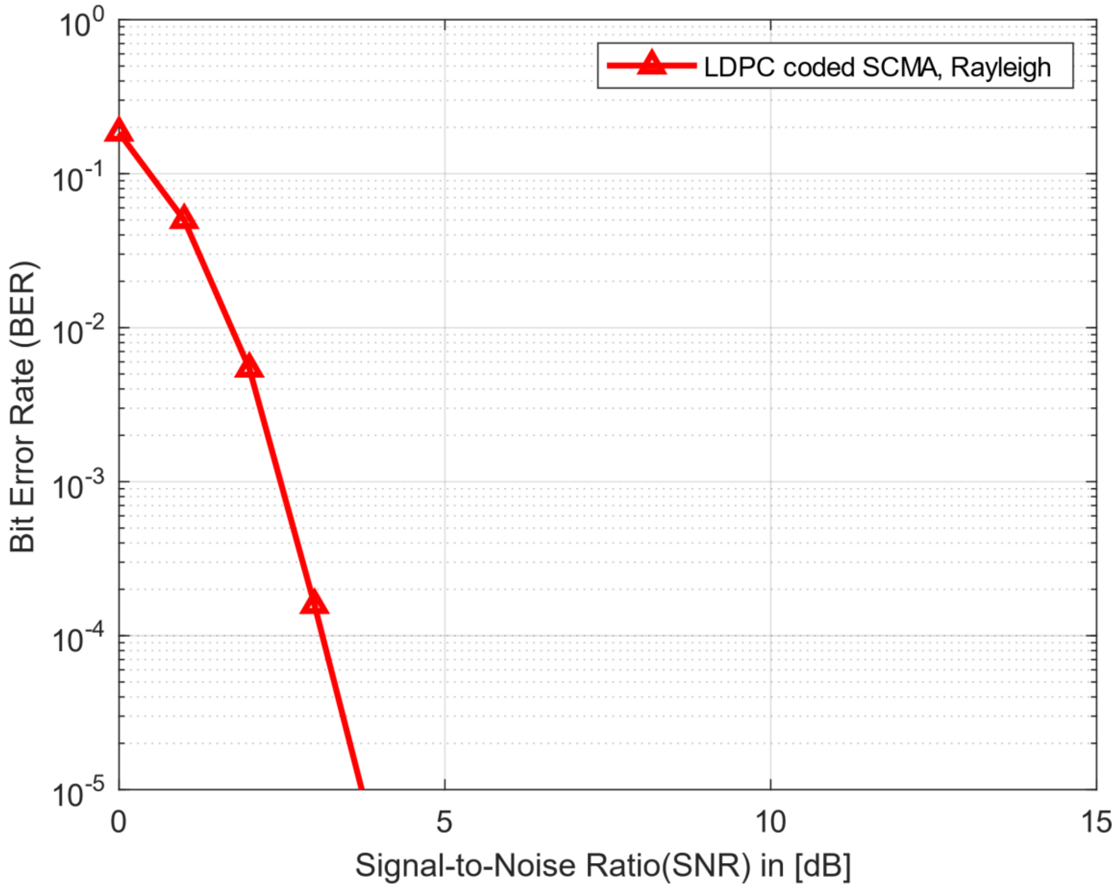

Figure 5. 8: SNR vs BER performance of LDPC coded SCMA

Figure 5.8 shows the BER performance of low density parity check coded sparse code multiple access (LDPC coded SCMA). As the figure also depicts that regarding LDPC coded SCMA, the curve starts approximately from BER = 1×10^{-1} when SNR = 0 dB and reaches approximately BER = 10^{-5} at SNR = 4 dB.

5.2.5 Performance comparison of SCMA and LDPC coded SCMA

A promising option for next-generation wireless communications is offered by the suggested LDPC coded SCMA [3]. Low density parity check code scheme is the best that we know of analysing its bit error rate (BER) performance which is visually represented through graph. The results of SCMA and LDPC coded SCMA simulation are as follows:

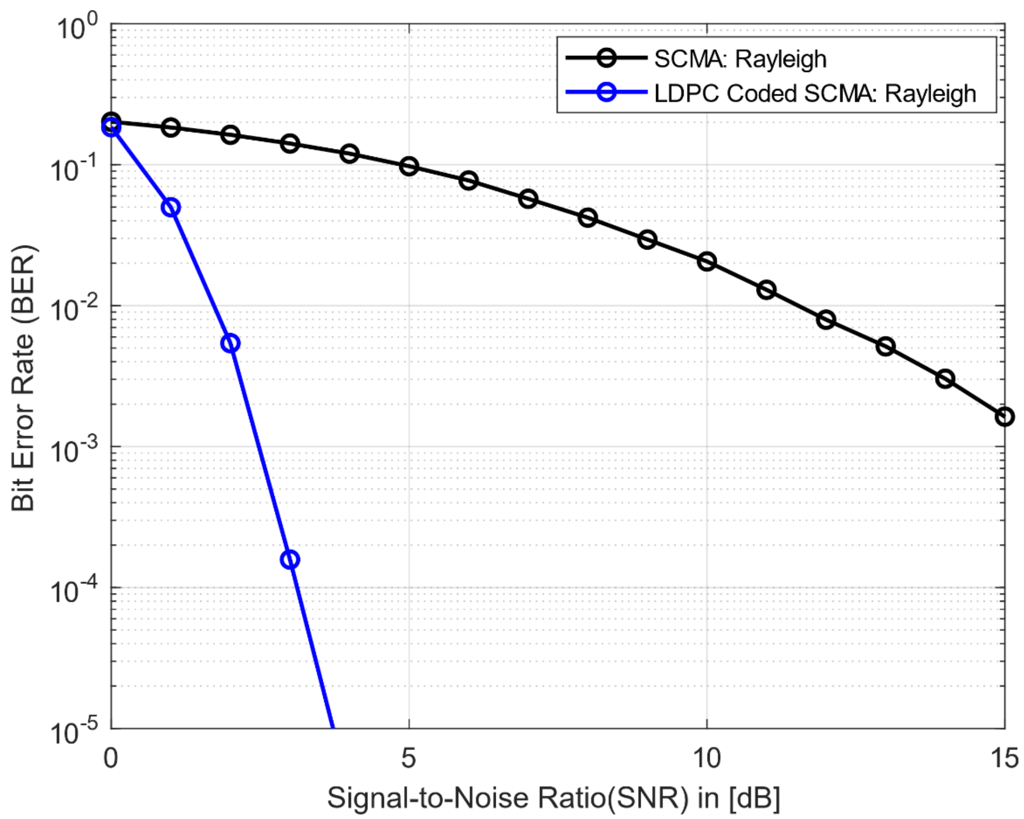

Figure 5. 9: BER performance of SCMA and LDPC coded SCMA

Figure 5.9 shows the BER performance of sparse code multiple access (SCMA) and low density parity check coded sparse code multiple access (LDPC coded SCMA). As the figure depicts that regarding SCMA, the curve starts approximately from BER = 1×10^{-1} and SNR = 0 dB and reaches approximately at BER = 7×10^{-5} and SNR = 15dB. On the other hand, as the figure also depicts that regarding LDPC coded SCMA, the curve starts approximately from BER = 1×10^{-1} and SNR = 0 dB and reaches approximately at BER = 10^{-5} and SNR = 4 dB.

5.2.6 Comparison of SCMA, Polar coded SCMA and LDPC coded SCMA

The results of SCMA, Polar coded SCMA and LDPC coded SCMA simulation are shown in figure 5.10.

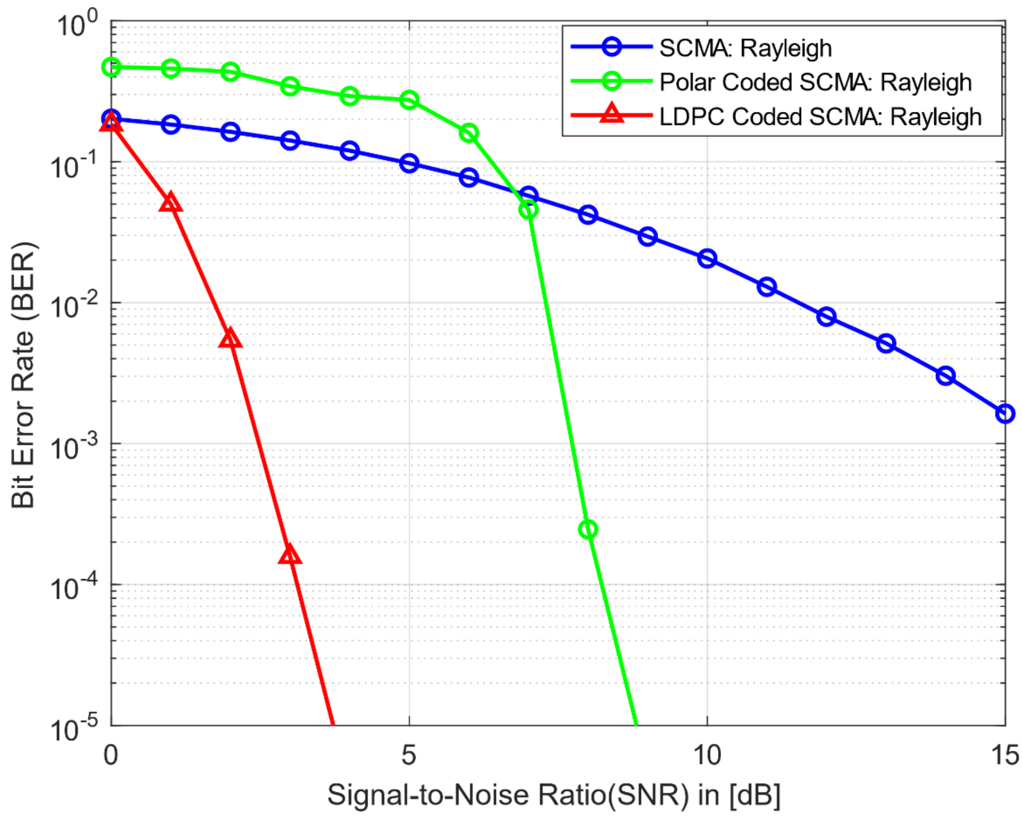

Figure 5. 10: BER performance of SCMA, Polar coded SCMA and LDPC coded SCMA

Fig 5.10 shows the BER performance of sparse code multiple access (SCMA) and polar coded sparse code multiple access (Polar coded SCMA). As the figure depicts that regarding SCMA, the curve starts approximately from BER = 1×10^{-1} and SNR = 0 dB and reaches approximately at BER = 0.5×10^{-3} and SNR = 15dB. As the figure also depicts that regarding Polar coded SCMA, the curve starts approximately from BER = 4×10^{-1} and SNR = 0 dB and reaches approximately at BER = 10^{-5} and SNR = 9 dB . On the other hand, as the figure also depicts that regarding LDPC coded SCMA, the curve starts approximately from BER = 1×10^{-1} and SNR = 0 dB and reaches approximately BER = 10^{-5} at SNR = 4 dB . So, it is obvious that LDPC coded SCMA is better than SCMA, Polar coded SCMA.

5.3 Performance comparison of Different Multiple Access Schemes

LDPC coded SCMA is also better than OFDM, OFDMA, MC-CDMA. The simulation results of OFDM, OFDMA, MC-CDMA, SCMA, Polar coded SCMA and LDPC coded SCMA are represented in figure 5.11.

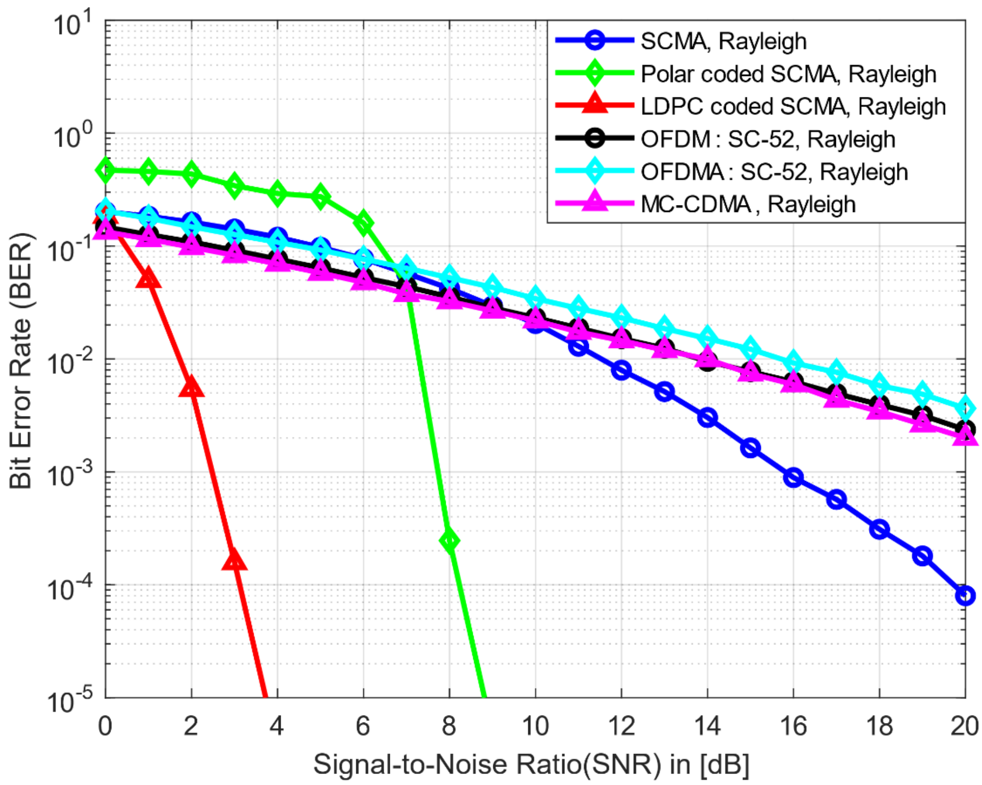

Figure 5. 11: BER performance of Different Multiple Access schemes

Figure 5.8 shows the BER performance of OFDMA, OFDMA, MC-CDMA, SCMA, Polar coded SCMA, LDPC coded SCMA. As the figure depicts that regarding OFDM, the curve starts approximately from BER = 1×10^{-1} and SNR = 0 dB and reaches approximately at BER = 2.5×10^{-3} and SNR = 20 dB and in terms of OFDMA, the curve starts approximately at BER = 0.5×10^{-1} and SNR = 0 dB and reaches approximately BER = 1×10^{-3} and SNR = 20dB. On the other hand, as the figure depicts that regarding multi carrier code division multiple access (MC-CDMA), the curve starts approximately from BER = 0.5×10^{-1} and SNR = 0 dB and reaches approximately at BER = 1×10^{-3} and SNR = 20 dB. As the figure depicts that regarding SCMA, the curve starts approximately from BER = 1×10^{-1} and SNR = 0 dB and reaches approximately at BER = 0.5×10^{-3} and SNR = 15dB. As the figure also depicts that regarding Polar coded SCMA, the curve starts approximately from BER = 4×10^{-1} and SNR = 0 dB and reaches approximately at BER = 10^{-5} and SNR = 9 dB. On the other hand, As the figure also depicts that regarding LDPC coded SCMA, the curve starts approximately from BER = 1×10^{-1} and SNR = 0 dB and reaches approximately at BER = 10^{-5} and SNR = 4 dB.

5.4 Summary

Our simulation results show that our suggested system perform better than other multiple access techniques. Here, we show the performance of orthogonal frequency division multiplexing (OFDM), orthogonal frequency division multiple access (OFDMA) and multi carrier code division multiple access (MC-CDMA). We have demonstrated that multiple access technique is better for multiple user in wireless communication. We have discuss the bit error rate performance of sparse code multiple access and polar coded SCMA. We have shown that polar coded SCMA perform better than SCMA. We have also examined that our system performance using various simulation parameters such as maximum number of bits, minimum number of bits, and number of iteration. We have also demonstrated that, bit error rate (BER) performance is better than others. LDPC coded SCMA shows better performance. Low density parity check coded sparse code multiple access scheme have perform better all of the other multiple access scheme LDPC coded SCMA is a capacity approaching code which can easily reduce the bit error rate.

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[1] R. Prasad and S. Hara, "An overview of multi-carrier CDMA," in *Proceedings of ISSSTA'95 International Symposium on Spread Spectrum Techniques and Applications*, 1996, vol. 1: IEEE, pp. 107-114.

[2] Z. Pan, E. Li, L. Wen, J. Lei, and C. Tang, "Joint iterative detection and decoding receiver for polar coded SCMA system," in *2018 IEEE International Conference on Communications Workshops (ICC Workshops)*, 2018: IEEE, pp. 1-6.

[3] W.-C. Sun, Y.-C. Su, Y.-L. Ueng, and C.-H. Yang, "An LDPC-coded SCMA receiver with multi-user iterative detection and decoding," *IEEE Transactions on Circuits and Systems I: Regular Papers*, vol. 66, no. 9, pp. 3571-3584, 2019.

Chapter 6

Future Work and Conclusion

6.1 Summary

In this chapter, we conclude the overall work contained in this thesis. In chapter One, we have described about wireless communication technology and a brief description of the multiples access technologies in the communication systems along with proper literature survey. The motivation, contributions and finally expected outcomes of the thesis are also included in this chapter.

In chapter two, we have described various related works in our thesis regarding the names of the authors, published year, the objectives of the study, the distinctiveness of the research papers and the final outcomes.

In chapter three, we have described single carrier modulation, its advantages and disadvantages, a quick survey on the different antenna terminology, various multicarrier modulation schemes including system overview, block diagram, advantages, disadvantages and so on of OFDM, OFDMA, MC-CDMA system in detail associated to the thesis work.

In chapter four entitled sparse code multiple access techniques, which is the main body of this thesis introduced the LDPC coded SCMA system. We have described the methodology of SCMA system, polar coded SCMA system and finally the LDPC coded SCMA system which explains the synthesis of LDPC encoding and decoding of SCMA system, symbol identification, block diagram, mathematical expression in this study.

In chapter five, the analysis of BER with respect to SNR is described with various parameters. We have also compared the performance of OFDM, OFDMA, MC-CDMA, SCMA, polar coded SCMA, LDPC coded SCMA with each other.

In chapter six, we describe the summary of the overall thesis, future work and conclusion.

6.2 Future Work

The performance analysis of the different multiple access techniques can be optimized in future by implementing comprehensive experiments. A number of experiment can be done:

- Different types of error correcting codes such as Hadamard code, Reed Muller codes, Reed Solomon codes can be implemented in the system.
- Various types of channel such as additive white Gaussian noise (AWGN), flat-fading channel, multi-path fading can be adopted for exploring the performance of LDPC coded SCMA.
- LDPC coded SCMA system's performance evaluation can be done by using constellation diagram analysis.
- Convergence analysis can be done by using an extrinsic information transfer (EXIT) chart for the better performance analysis.
- Different types of decoding algorithm such as list sphere decoding, Max log MPA multiuser detection algorithm can be implemented to analysis the better performance.

6.3 Conclusion

In this thesis, we presented the LDPC coded SCMA system for increasing the performance of the wireless system. We presented the combination of the SCMA detector and the LDPC decoding with almost the same complexity compared to un-coded SCMA system. The LDPC coded SCMA system has advantages when channels are complicated by significant distortion and interference, and also reduce the bit error rate. The simulation results demonstrate the efficiency and improved performance of the proposed system. For high data rate, better channel performance, low bit error rate, low interference among multiple users, the proposed system is effective for the present wireless communication techniques.