Hybrid PD-NOMA and SCMA Scheme for massive Machine Type Communication

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DEDICATION

In the pursuit of completing this thesis, I have been fortunate to be enveloped by an unyielding network of support and encouragement from the dearest individuals in my life. Their unwavering belief in my capabilities has served as a guiding light through every twist and turn of this academic journey.First and foremost, I dedicate my thesis work to my parents, who consistently provided encouragement and unwavering support. Their unconditional love,sacrifice and exemplary guidance have instilled in me the value of hard work and determination in pursuit of my aspirations.

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Abstract

Massive machine type communication (mMTC) has emerged as a key driver for societal digitalization, promising connectivity to a vast number of devices, reaching up to $10\,\mathrm{M/km^2}$. However, conventional cellular systems struggle to efficiently handle the massive influx of short packet transmissions inherent to mMTC. Non-Orthogonal Multiple Access (NOMA) presents a promising solution by allowing multiple users to share the same resources. This paper explores the integration of Power-Domain NOMA (PD-NOMA) and Sparse Code Multiple Access (SCMA) to superimpose extra users having different quality of service requirements, on the SCMA multiplexed signal in a spectrally efficient manner. The proposed hybrid system demonstrates increased spectral efficiency, enhanced overloading capability, reduced receiver complexity as compared to traditional NOMA and SCMA systems.

Keywords:massive Machine Type Communication (mMTC),Non-orthogonal multiple access (NOMA),Power-Domain NOMA(PD-NOMA), Sparse Code Multiple Access (SCMA).

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LIST OF ACRONYMS

OMA Orthogonal Multiple Access

NOMA Non-Orthogonal Multiple Access

PD-NOMA Power Domain-Non Orthogonal Multiple Access

SCMA Sparse Code Multiple Access

mMTC massive Machine Type Communication

SIC Successive Interference Cancellation

MPA Message Passing Algorithm

BER Bit Error Rate

SE Spectral Effeciency

AI Artificial Intellegence

QoS Quality of Service

GSM Global System for Mobile Communication

CDMA Code Division Multiple Access

1G 1st Generation

2G 2nd Generation

3G 3rd Generation

4G 4th Generation

5G 5th Generation

SMS Short Message Services

UMTS Universal Mobile Terrestrial / Telecommunication System

LTE Long Term Evolution

RAN Radio Access Networks

IoT Internet of Things

VR Virtual Reality

mTCDs machine-Type Communications Devices

FDMA Frequency Division Multiple Access

WDM Wavelength Division Multiplexing

AR Augmented Reality

LDS-CDMA Low Density Signature-Code Division Multiple Acces

LDS-OFDMA Low Density Signature-Orthogonal Frequency Division Multiple Access

BW Band Width

BS Base Station

Chapter 1

Introduction

Driven by the need to increase productivity and efficiency, there has been a noticeable upsurge in the digitalization of our sectors and societies in recent years. The creation of smart cities with intelligent waste and traffic management systems, the adoption of e-healthcare technologies that allow for patient monitoring from a distance, and developments in agricultural technology all demonstrate this tendency. These technological developments have made our lives easier, more productive, and more connected.
The way we interact and communicate has been profoundly changed by the tremendous advancements in technology. Our connected world has changed significantly, from the ubiquitous use of cell phones to the rise of virtual reality and artificial intelligence (AI). Particularly in the case of mobile communications, these have changed from being predominantly human-centric to supporting machine-centric applications.
A major turning point was the introduction of 5G technology, which was created to accommodate this changing environment. It is anticipated that the upcoming 6G technology will expand on this base in the future, pushing the limits of technological innovation and connectivity.
Undoubtedly, one of the communications technologies that has grown the fastest in the previous ten years is wireless communication networks. Globally, communication networks are constantly redefining many aspects of work and life in society. The proliferation of Internet of Things (IOT) devices is laying the groundwork for a vast array of end-to-end user applications, which have grown exponentially in the last several years. One of the many services that may be accessed on a mobile device is the internet.
It is widely acknowledged as a key technology of the information era. The ability to communicate in several modes and across geography and time is made possible by the Internet. Applications for seamless, sophisticated, and dependable real-time data collecting and processing in the sectors of medicine, commerce, security, entertainment, education, research, science, and engineering are available on today's smart gadgets. These applications from service providers require specific quality of service (QoS) requirements, such as high data rates, low power consumption, ultra-low latency and

ultra-dependability, high mobility, radio resource sharing, and massively networked devices. In the long run, mobile connectivity is more of a necessity than a luxury for maintaining a respectable standard of contemporary.

1.1 Evolution of Wireless Networks

The first wireless communication in history was employed by an Italian inventor Macroni. Ever since engineers have been trying to figure out how to use radio frequency waves more effectively. The use of wired telephones was already common by the middle of the 1800s. Scientists were already creating gadgets that used radio waves to transmit audio instead of a cable link because of its limited mobility. The first mobile handheld gadget prototype was created in the middle of the 1970s. This was considered to be the pivotal moment in wireless communications, resulting in the advancement of standards and technologies [34].

Rapid improvements in mobile communication standards were required due to the growing need for additional connections globally. In the 1980's the 1G used analog switching technology with a 10 MHz bandwidth constraint to transmit exclusively speech signals between the frequencies of 800 and 900 MHz. Nevertheless, 1G had drawbacks such as poor speech quality of service because of severe interference, with a limited number of users and low cell coverage, small battery life and security concerns [31].

In the late 1980's the Global System for Mobile Communication (GSM) technology introduced the second generation (2G) of mobile communications and went on to become a global wireless standard. In addition, improved the voice transmission quality, i.e., from 14.4Kbps to 64 Kbps maximum data rate supported by the GSM standard was sufficient for email and short messaging services (SMS). Code Division Multiple Access (CDMA) technology was introduced in the middle of the 1990s and showed improvements in data rate, number of connected users, and spectrum efficiency. Additional advancements produced what were dubbed 2.5G and 2.75G, which brought about the creation of CDMA2000, Enhanced Data GSM Evolution (EDGE), and General Packet Radio Service (GPRS). For GPRS data rate was increased to 171kbps, for CDMA2000 384 kbps and EDGE 473.6 kbps respectively [19].

The third generation (3G) of mobile communications has a data rate of 384 kbps. Multimedia chat, e-mail, video calls, games, social media, location monitoring, mapping, and healthcare were all good uses for 3G. Technological advancements were implemented to improve QoS which resulted in 3.5G and an increase in data rate to 2 Mbps. The 3.75G network uses High-Speed Packet Access plus technology to improve upon the 3G network. However, the introduction of 3G was beset by costly spectrum licensing, stringent bandwidth requirements, incompatibilities with earlier technologies, and exorbitant expenses for devices, infrastructure, and deployment [29].

The fourth generation (4G) was developed by IEEE, provided higher data rates, i.e., up to 1 Gbps, and supported more sophisticated multimedia services. 4G transmits data and voice-over internet-protocol (VoIP) packets in both the uplink and downlink directions simultaneously using sophisticated modulation techniques and carrier aggregation. Improved security, mobility, lower latency, high definition (HD) gaming and streaming and improved voice over Long Term Evolution Network VoLTE are some of the main advantages of 4G. Nevertheless, 4G continues to face obstacles such as high spectrum costs, time-consuming upgrades, expensive end-user mobile devices, and infrastructure installation expenses [11].

1.2 5th Generation Networks

Fifth generation (5G) mobile communications, which are now in the experimental stage, hold great potential for offering very fast internet, a multimedia experience for users, low latency and crucial mission-critical applications, enhanced security, and mobility. To increase capacity and spectrum efficiency, 5G makes use of heterogeneous cells, non-orthogonal multiple access, beam shaping, and cloud-based infrastructure. This research considers architectural alternatives and improvements to multi-radio access approaches with the goal of improving the capacity and spectral efficiency of 5G networks. With the use of a more intelligent design, 5G eliminates the need for complicated infrastructure or base station proximity restrictions on Radio Access Networks (RANs). Dis-aggregated, adaptable, and virtual RAN is the direction that 5G is taking, with new interfaces generating more data access points.

1.3 5G Application Scenario

The big telecom companies are under a lot of pressure to outline the essential 5G needs, which include enhancing cellular network design to handle issues with higher capacity, better data rate, reduced latency, disposable connectivity, and strong quality of service. As per mobile and wireless communications enablers [17] 2020, [5] 5G provides three broad generic services and they are explained below [27].

1.3.1 Enhanced Mobile BroadBand(eMBB)

5G Non-Standalone installations initially concentrate on eMBB, which offers higher data-bandwidth together with modest latency reductions on 4G LTE and 5G NR (5G new radio). This will support the development of current mobile broadband use cases, including 360-degree or UltraHD video streaming, upcoming AR/VR media and applications, and many more.

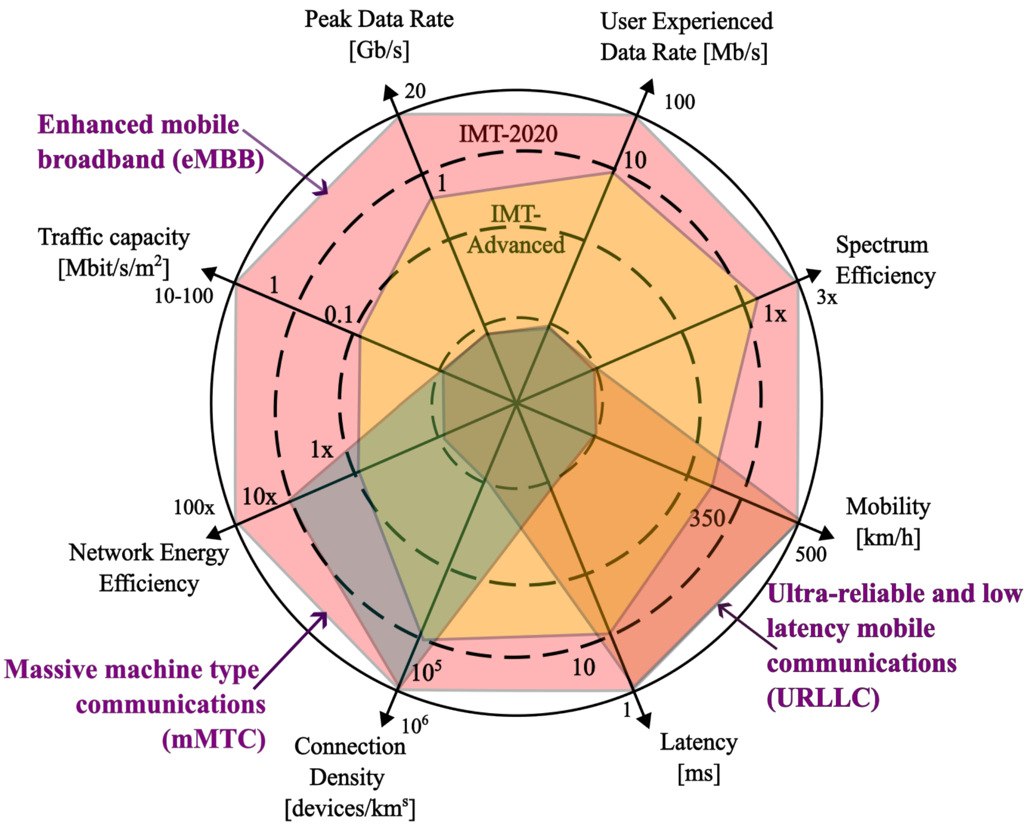

Figure 1.1: 5g requirements

1.3.2 Long Distance and High Mobility Communication

LDHMC stands for Long Distance and High Mobility Communication.5G wireless communication is expected to carry a high data rate and huge number of connections to achieve better spectrum efficiency and energy efficiency, in addition to improving quality of service (QoS), data security, and transmission latency. Moreover, the 5G network must include strong mobility requirements who is traveling at very high speeds. 5G should support mobility on demand to low mobility or immobilized devices.

1.3.3 massive Machine Type Communication (mMTC)

One of the main services that 5G and beyond wireless communication provide is massive Machine Type Communication (mMTC) and it is used to connect a large number of devices, i.e., up to 10M/km^2. It sends data in the form of short packets. It was designed primarily to make it possible to simultaneously gather a massive amount of

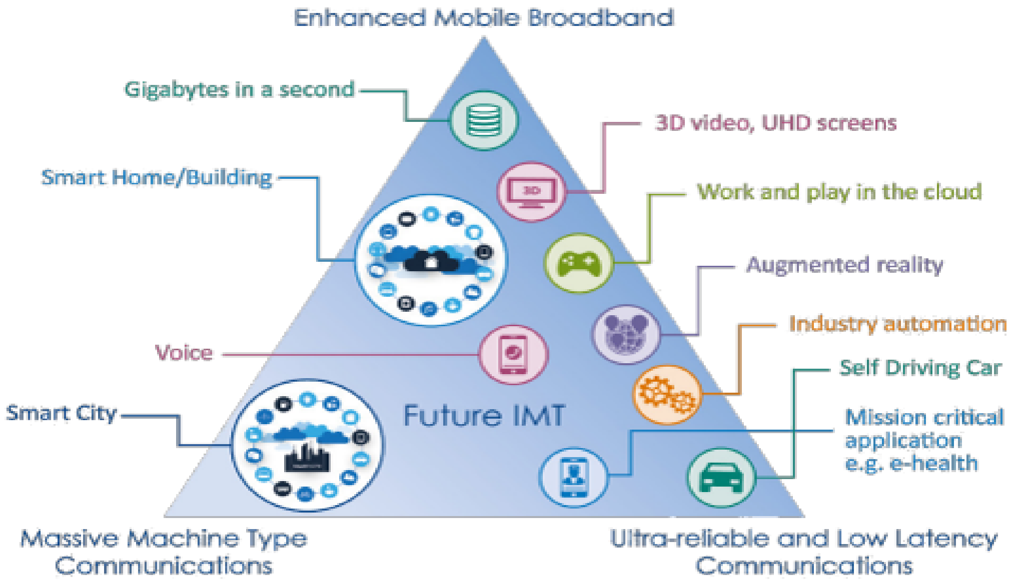

Figure 1.2: Enhanced Mobile BroadBand (eMBB) applications

tiny data packets from a large number of devices. Applications utilizing Internet of Things (IoT) sensors are supported by mMTC, which means that data can be used to save energy costs, increase productivity, or enhance our lives in different ways. It is anticipated that this would revolutionize the IoT sector. It attempts to satisfy other IoT application's needs for smart cities. Up to one million devices can be connected in a square kilometer using mMTC. Compared to 4G LTE network capability, this is five times higher. With this capability, 5G can offer the framework required to accommodate massive networks of sensors connected to cellular networks.
A large number of IOT devices are connected to send data in short packets sporadically and are intended to use the mMTC service area. These gadgets must have a longer battery life up to ten years. IoT sensors provide data packet transmission up to 10 kilometers and are used for smart cities to control traffic, e-health care systems to monitor patients, and smart agriculture where farmers can optimize irrigation frequency and volumes to ensure high crop yields. However, these sensors would not work in remote areas, underground or with high latency networks connecting them.
Regarding future communication new requirements must be considered in the field of growing mMTC. A network of low-power heterogeneous devices communicate with each other and the generated information is sent to a central hub for analysis, which is then shared with systems like PCs. It is one of the main enablers for increasing demand of digitization of our societies. In mMTC, data is transmitted sporadically and has different requirements than traditional LTE applications. Therefore, providing massive connectivity to a large network of such devices is a challenging task.

In massive Machine Type Communication transmission is not done adequately in cellular system for large number of devices as it face some challenges [24].

1.4 Challenges in massive Machine Type Communication

There are some key challenges in massive Machine Type Communication and they are as follows:

1. Scalable and efficient connectivity
2. Energy efficiency
3. Interference management
4. Transmission latency and reliability

1.5 Multiple Access (MA)

Multiple access schemes allow several users connected to the same transmission medium to share a finite amount of resources at the same time. It plays a vital role in improving the cellular network. To improve system capacity it is very important that how multiple access scheme is designed.

1.6 Multiple Access Techniques

Any given area is divided into cells by a cellular system, and each cell's mobile units connect with the nearest base stations. The primary goal of cellular system design is to enhance the channel's or system capacity or the ability to process the data transmission with an adequate degree of quality of service in a given bandwidth. Different types of MA schemes, as given in Fig. 1.3, are explained subsequently.

1.6.1 Orthogonal Multiple Access (OMA)

By multiplexing the data or information signals from many users, orthogonal multiple access (OMA) enables several users to share resources without interfering with one another in terms of time, frequency, or coding. The operational modes, designs, algorithms, services, applications, and multiple-access techniques of communications

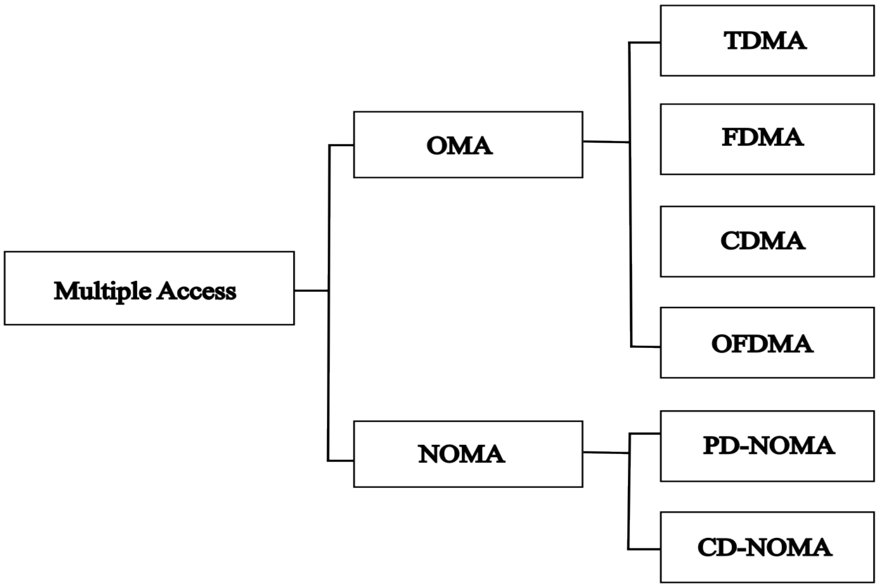

Figure 1.3: Types of MA techniques

systems set them apart. The intention is to support a high number of users in order to enable concurrent access to the resources. Several multiple-access techniques can be used to mitigate interference with other users by multiplexing users and sharing resources in terms of time, frequency, or code [22]. The most popular OMA techniques are described below.

1.6.1.1 FDMA

In FDMA technique, the available channel or bandwidth is divided into small chunks of bands/ sub-bands (sub-carriers) for exclusive use by a single user, as shown in Fig. 1.4. The width of each band is enough to support the signal spectra for the transmissions of data to be transmitted. Each sub-carrier is then modulated using the message signal and is linearly blended with the rest of the sub-carriers [28].

For example, a single coax cable in a cable television system serves as the medium to carry hundreds of channels. The total bandwidth of the coax cable is separated into sub-channels, this separated BW was first utilized by a single TV station or channel. However, today's digital systems allow numerous TV channels to use the same medium because each channel's data is modulated on different carrier frequencies and further

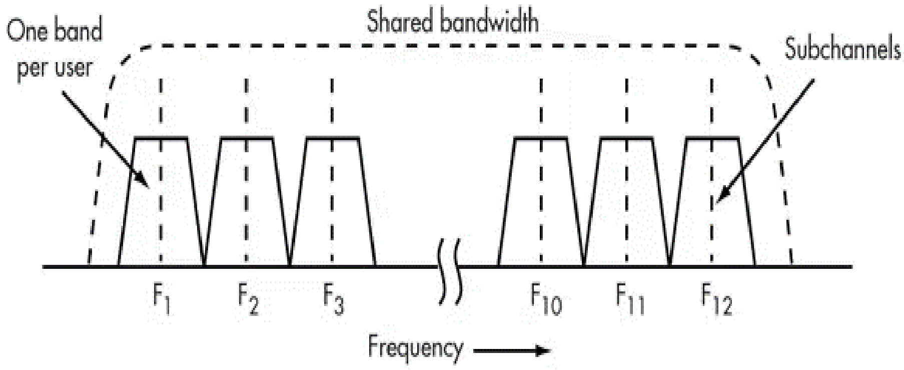

Figure 1.4: FDMA .

processed using compression and multiplexing techniques.
Systems for fiber optic communications also employ this method. Massive bandwidth can be divided inside a single fiber optic connection to enable FDMA. In the original analog telephone system, which was one of the oldest FDMA systems, the frequency multiplex technique was used to put all phone calls on a single line. 12 channels with subcarriers modulated by using analog voice signals from 300 Hz to 3400 Hz.

1.6.1.2 TDMA

In TDMA, a single channel is divided into different time slots and each time slot is allocated to a single user. Data of each user in sequential format is transmitted throughout each time slot. This method is helpful for high-speed data such as compressed video but it also performs well with slow voice data transmissions [14].
GSM (Global System of Mobile Communications) is based on TDMA technique. It uses time division techniques in such a way that it can group eight voice calls into a single channel. One frame of a GSM TDMA signal is displayed in Fig. 1.5. Data such as voice signals, emails, and short message service (SMS) can be sent within the eight-time interval.

1.6.1.3 CDMA

CDMA is another entirely digital technology, it scatters a digitized analog signal over a wider bandwidth at a lower power level. Unique codes/symbols are mapped to spreading sequences that are orthogonal to each other and they are allotted to different users for data transmission. This technology permits several users to send and receive through a single channel. Each part of the data is labeled with a specific code. The resultant signal is low strength and has a noise-like appearance. A correlating circuit at the receiver recognizes and recovers a particular user code [1].

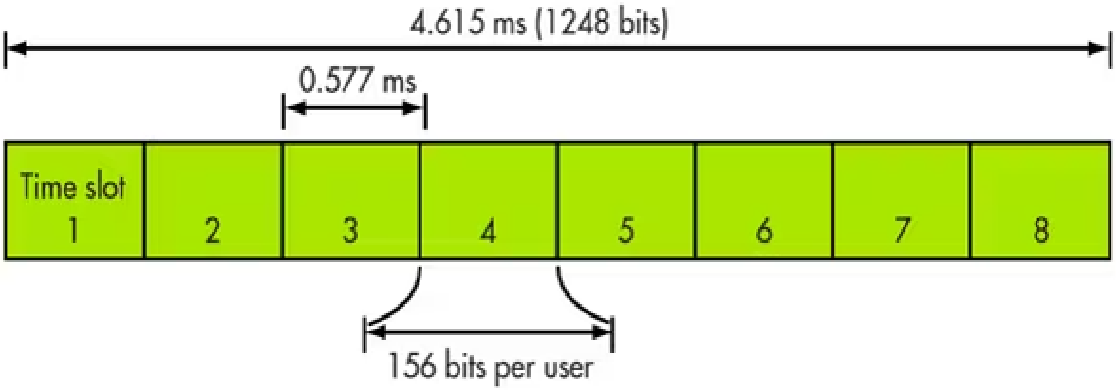

Figure 1.5: GSM frame

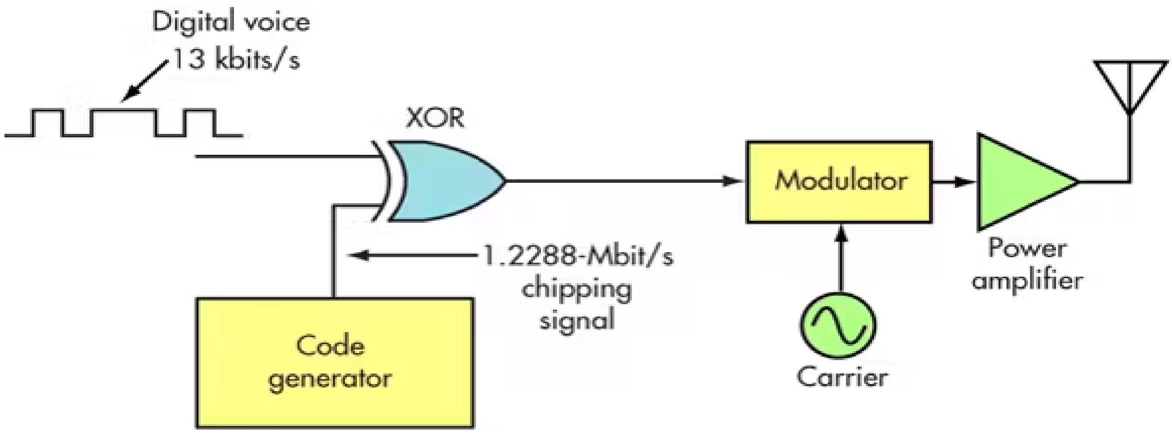

Figure 1.6: CDMA

1.6.1.4 OFDMA

OFDMA technique allows numerous users to share a given bandwidth orthogonally. It divides a channel into several narrow-band orthogonal sub-channels which don't interfere with each other. The data that has to be transferred is packaged using time slots found in each sub-channel data stream. Due to its excellent spectral efficiency, this method offers exceptionally high data rates. Additionally, multi-path propagation effects have less of an impact [46].

1.6.1.5 Limitations of OMA

- The number of users can not exceed the number of available resources

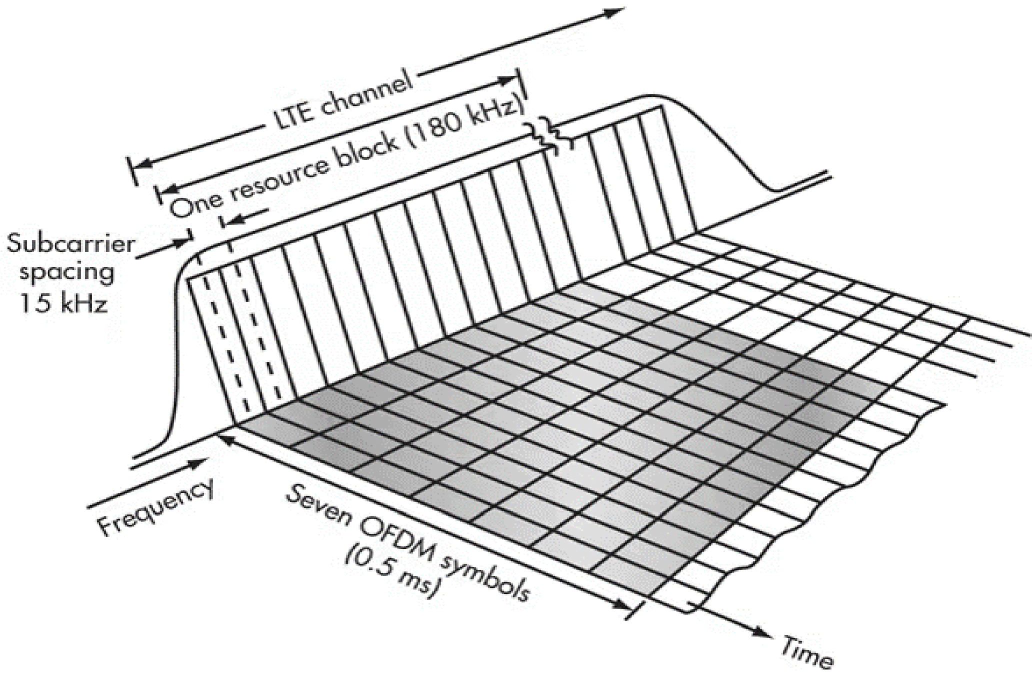

Figure 1.7: OFDMA

- Spectrally inefficient for Ultra mMTC

1.7 Non-Orthogonal Multiple Access (NOMA)

NOMA is a kind of multiple-access technology that offers low end-to-end transmission latency, enhanced throughput, relaxed channel feedback, and increased spectral efficiency (SE). It also allows the simultaneous allocation of one resource to several users. For attaining good system-level throughput performance, OMA is a practical solution. But because of the previously mentioned impending wave, the 5G network system needs to improve system efficiency. In light of this, scientists from all around the world have begun looking into NOMA as a future and have started putting their efforts into this technique. The transmission strategy can automatically be adjusted by NOMA based on the traffic and the CSI of its users. It can therefore reach the advantageous operating point where energy efficiency and spectrum efficiency are at their peak [33]. Many devices can connect to the network concurrently over the same time/frequency resource in NOMA. A viable plan for ultra mMTC is NOMA. It is spectrally efficient for mMTC. The NOMA can be divided into two primary categories:

- Power Domain NOMA
- Code Domain NOMA.

1.7.1 Power Domain NOMA

In the power domain NOMA, unique power ranks are assigned to different users according to their distance from the base station and their channel condition. The user who is far away from the base station is assigned with a high power rank as it has poor channel condition and the user who is near the base station is assigned a lower power rank as it has good channel condition. To transmit the signal, signals from different users are superposed and the resulting signal is then transmitted over the same channels, i.e., the same time-frequency resources by using superposition coding (SC) at the transmitter side. By this method information to multiple recipients at once from a single source can be sent.
At the receiving end, to decode the data, the user which is far away from the base station, direct detect and decoding is applied on it as the highest power rank is assigned to it and it will consider near user signal as noise. Moreover, the user who is near to base station undergoes successive interference cancellation (SIC). In SIC, the near user decodes the signal of the far user while considering it as noise. The decoded signal is subtracted from the total received signal and the near user signal is decoded from the residual signal [19].

1.7.2 Code Domain NOMA

Code domain NOMA allows the sharing of common time and frequency among users. Identification at the receiver is performed based on user-specific non-orthogonal codes by using Multi-User Detection (MUD) techniques. Different types of CD-NOMA, as depicted in Fig. 1.8, are sparse code multiple access (SCMA), low-density signature orthogonal frequency division multiple access (LDS-OFDMA), and low-density signature-code division multiple access (LDS-CDMA). SCMA employs device-specific codebooks, while LDS-CDMA and LDS-OFDMA use non-orthogonal real/complex spreading sequences. Depending on the needs of the system, huge connectivity can be enabled via SCMA approaches.
Multiple input bits/symbols in SCMA are directly mapped to a sparse code word that is taken from a predefined code book. To decode the transmitted data or information MPA is applied in SCMA. It operates more effectively when there is noise. Although the precise implementation and optimization of crucial aspects like power allocation, code design, and receiver algorithms determine the overall performance of both CD-NOMA and PD-NOMA, CD-NOMA generally performs better [26].
Higher spectrum efficiency is offered by both PD-NOMA and SCMA.With the increased number of users Bit Error Rate (BER) also increases and the complexity of the receiver increases exponentially. The proposed research is to combine sparse code multiple access (SCMA) and PD-NOMA in order to maximize the benefits of both NOMA schemes by increasing the number of connected users and enhancing spectral

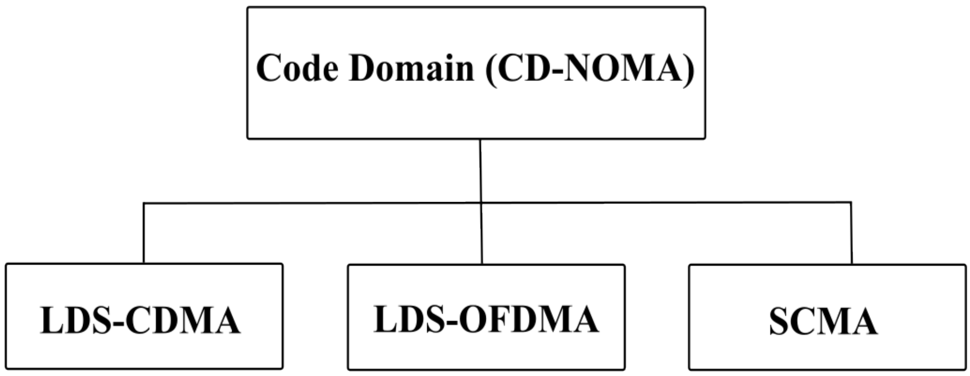

Figure 1.8: Types of CDMA

efficiency. The objective of the research work is to efficiently use the spectrum to superimpose additional customers with varying quality of service requirements on the SCMA multiplexed signal. The additional users will be supported with various power levels and modulations within the current SCMA resources. Compared to the traditional SCMA scheme, the proposed scheme will be less complex and have a higher overloading capability.

1.7.3 Problem Statement

mMTC are expected to play an essential role in 5G and beyond wireless systems, whose traffic profile is typically a small amount of data (spread) sporadically. With its low-latency connections and high capacity, it is expected to transform the IoT industry. It is over ten times higher than 4G LTE network capability.mMTC can be utilized to lower energy usage, increase productivity, or enhance our lives in various ways such as smart cities, smart buildings, health care, farming and agriculture, etc. Scalable and effective connectivity for a large number of devices transmitting extremely small packets is one of the primary challenges in mMTC, and this is something that cellular networks cannot manage properly designed for human-type communications.

The proposed method will help in providing significant improvement in meeting the requirements of future wireless communication systems (5G and beyond) by increasing the number of users served, improving the overload factor, and reducing the complexity as compared to what has been proposed in previous research already carried out in this domain.

1.7.4 Objectives

The following list comprises this study's objectives:
a. To improve spectral efficiency.
b. To improve BER.
c. Reduce complexity.
d. To increase system capacity or overload factor.

1.7.5 Area of Applications

a. Smart Cities
b. Smart Buildings
c. Healthcare
d. Intelligent Transport Systems
e. Farming and Agriculture
f. Manufacturing
g. Smart Grids

1.7.6 Relevation to National Needs

Regarding future communication system, new requirements must be considered in the field of growing massive machine type communication in Pakistan. Pakistan is regarded as one of the world's most populous nations. As a result, it is imperative that technology be used to its full potential for the nation's digital transformation. The ability to produce goods and services more efficiently, which is made possible by technological innovation, is a prerequisite for prosperity. The main areas to focus on are contemporary methods for managing massive data sets and spectrally efficient ways to enable a huge number of sensor devices to connect to wireless networks. The implementation of enormous connectivity and enhancing spectral efficiency are the main topics of discussion in literature.

1.7.7 Organization of Thesis

Six chapters make up the structure of the thesis chapters. A brief overview of wireless networks, their uses, their specifications, enormous machine-type communication, and various access approaches is provided in Chapter 1. The overview of PD-NOMA and SCMA, as well as a review of some of the literature on current methods, are covered in Chapter 2. In Chapter 3, the suggested system model is presented. The results and simulation are covered in Chapter 4. Chapter 6 wraps up and discusses next steps.

Chapter 2

Literature Review

In different era, different technologies has been used according to the requirements and demands of the users. Time by time technologies have been improved. Different generations have different demands and requirements. To communicate different techniques have been used and multiple access scheme is one of the core technique to improve the cellular network. For massive connectivity in machine-type communication, we need to design a multiple access scheme that can accommodate such large umber of users simultaneously. Due to massive connectivity, several problems occur in connectivity for example firstly due to large number of users scalability and efficient connectivity is not done properly. Secondly as number of users will increase in future the it is difficult to handle interference management so an efficient multiple-access technique is required to overcome this problem. Thirdly due to massive number of users it will be difficult to detect the intruder who can hack the data.Therefore, it is very important to develop a well-planned multiple access technique which can detect the intruder in massive connectivity and the receiver receives the original data. Nowadays generation demands high quality services for communication with reduced transmission latency.
To overcome the obstacles seen in OMA technique, to accommodate large number of users, NOMA techniques being focused by researchers from all over the world to meet the new requirements, i.e., high data rate and traffic etc for 5G and beyond wireless communication system. NOMA is being prioritized for next-generation communication system as this system requires high data rate, low transmission latency and ultra reliable data [44].Considering such demands for future communication system Multiple Access technique is one of the core technique which is designed in such a way that it aims to enable several users to gain access to the network simultaneously over same time and frequency resource in a very effective way.To adapt to the evolving demands, new multiple access (MA) and modulation techniques are being developed [2].

2.1 5G Technical Requirements

5G has some technical requirements [36] and they can be summarised as follows:

- It is designed to transmit data at peak data rate which is 20 Gbps under error free conditions.

- The minimum peak spectral efficiency required by 5G for downlink transmission is 30 bit/s/Hz and for uplink transmission is 15 bit/s/Hz.

- The area traffic capacity considering geographic area for downlink transmission in 5G is 10Mbit/s/m^2 for indoor.

- In user plane latency total time for packet transmission for eMBB is 4ms and for URLLC is 1ms.In control plane latency idle state is separated from the beginning of transfering of data i.e 20ms.

- 1 million devices per km^2 is the connection density which is the minimum requirement for 5G system defined for mMTC.

- The mobility for defined QoS for minimum traffic channel normalized by BW should be 1.5 bits/s/Hz for 10 km/h , 1.12 bits/s/Hz for 30 km/h , 0.8 bits/s/Hz for 120 km/h and 0.45 bits/s/Hz for 500 km/h.

- The shortest time duration for mobility interruption in 5g is 0 ms in which user plane packets can not be exchanged.

- Bandwidth required in 5G is 100 MHz.

5G provides much more data rates as compared to previous techniques.It has greater connectivity density. Algorithm and MA techniques are designed in such a way that it provides very much reduces transmission latency and high spectral efficiency.

2.2 Multiple Radio Access Technologies

Radio access technologies have gone through under tremendous evolvement. For 1G FDMA technique was used, for 2G TDMA technique was used, for 3G CDMA was used and for 4G OFDMA technique was used [46]. These all techniques are type of multiple access techniques and each technique has different requirements for data transmission [6].

Further more, MA techniques has two types. Orthogonal Multiple Access techniques were used from 1st generation to 4th generation of network, which was designed to orthogonally allocate resources to multiple user. Due to limited number of resources OMA technique faces great challenges that it can not support massive connectivity and high spectral efficiency [10].
To overcome this problem NOMA techniques has been proposed which is another type of Multiple Access technique. NOMA is designed in such a way that it allocates resources in non-orthogonal manner among several users. In this way more users are supported which can access the time/frequency resource simultaneously anywhere and at anytime, at the expense of increased receiver computational complexity [23].
NOMA is categorized in two broad categories namely; power-domain NOMA, code-domain NOMA. To take advantage of PD-NOMA technique it is blended with SCMA which is type of Code domain NOMA (CD-NOMA) as it performs better in presence of noise, to make a hybrid technique.

2.3 Non-Orthogonal Multiple Access Schemes

In this section,NOMA basic principle is discussed in detail. Type of MA techniques are shown in figure 2.1. Resources are allocated in such a way that interference is controlled due to which NOMA is able to achieve overloading by multiplexing more users at the transmitter side and at the receiver side Multi-User Detection MUD is done to decode the data accuratley [37].

2.4 Data Transmission in PD NOMA

2.4.1 Superposition Coding (SC)

Consider a down-link scenario with two users with single antenna are placed at different distance from base station. The user which is far from base station, high power is assigned to that user due to its bad channel condition and the user which is near to base station low power is assigned to it as it has good channel condition. This is done in presence of AWGN and BPSK modulation. The channels are sorted as

$$0 < |h_2| \leq |h_1|$$

This indicates that far user will always hold weak channel i.e h_2 and near user will hold strong channel i.e h_1. At transmitter side superposition coding is done to transmit the information or data.Several users are multiplexed over the shared medium and utilize same time and frequency resource to send the data simultaneously and send the data

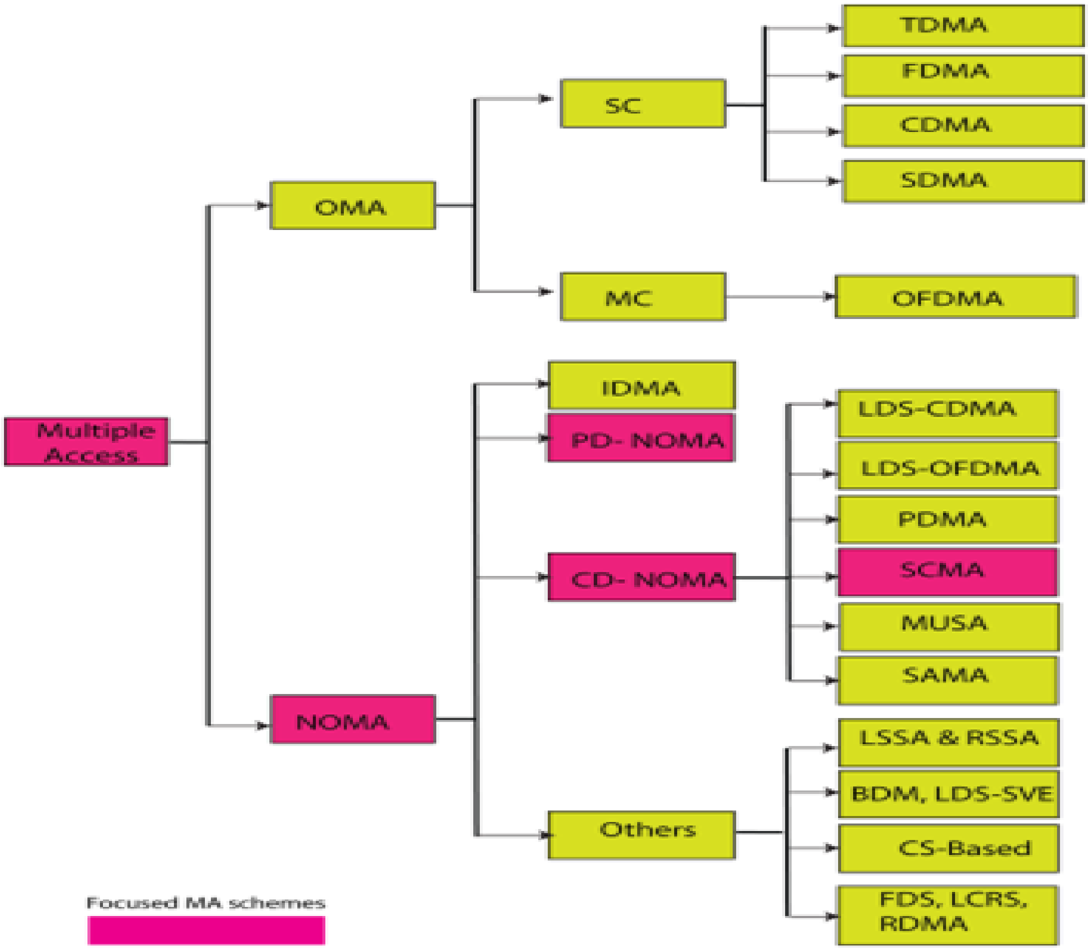

Figure 2.1: OMA and NOMA categories of multiple access

by using SC. S_1 and S_2 are the two output bit sequences,β_i represents a fraction of the total power P assigned to user i. Then output sequence is

$$X(n) = \sqrt{P\beta_1}S_1 + \sqrt{P\beta_2}S_2 \tag{2.1}$$

2.4.2 Successive Interference Cancellation (SIC)

Signal received at the user side or the reciever side is given below:

$$y_i = h_i x + w_i \tag{2.2}$$

Consider two users U_i,with $i = \{1, 2\}$ and all terminals are equipped with a single antenna ,where x is the superposed signal transmitted by the BS and $x = \sum_{i=1}^{N} \sqrt{P\beta_i}S_i$.

To decode the information or data at each receiver side direct detect and decoding is applied on far user as it has high power level. At far user, decoder decodes the data $S_1(n)$ by considering $S_2(n)$ as noise.
To decode the user near to the BS, SIC will be applied to remove the signal with high power. SIC is done in such a way that the near user which is to be decoded it will have some effect of far user signal to which it will consider as noise signal and subtract it from the signal of near user signal. Near user performs the following steps to decode its message from its received signal $Y_2(n)$:
a) Decode far user message $S_1(n)$ by using the single-user decoder.
b) Subtract $\sqrt{P\beta_1}h_2S_1(n)$ from the received signal $Y_2(n)$:

$$Y_2^{'} = Y_2(n) - \sqrt{P\beta_1}h_2S_1(n) \tag{2.3}$$

c) Decode near user data $S_2(n)$ by applying another single-user decoder [19].

2.5 Up-link and DowN-link PD-NOMA

There is a major difference between up-link and down-link PD-NOMA. First, in down-link, direct detect and decoding is applied on far user data with high power level and SIC is applied to near user to BS. In down-link MUD is more difficult than in up-link and in down-link far users are more impacted by intra-cluster interference. [21]
In uplink,the BS successively decodes near user signal and apply SIC to decode far user signal.In uplink transmission, near users are more likely to be impacted by the interferences from far users with high power level.

2.5.1 Passive Optical Network (PON)

The study of coherent passive optical networks, or PONs, is necessary to meet B5G criteria to enhance the system capacity and to reduce the end to end transmission latency.The system introduced in paper [38] was affected by granularity noise,so to remove this effect author used numerical simulation.

2.5.2 Secure Transmission in PD-NOMA

The authors in literature [25] worked on PD-NOMA with 4 users and explained the secured information transmission in PD-NOMA scheme for both up-link and down-link by spreading based technique. Authors also tried to reduce the complexity.

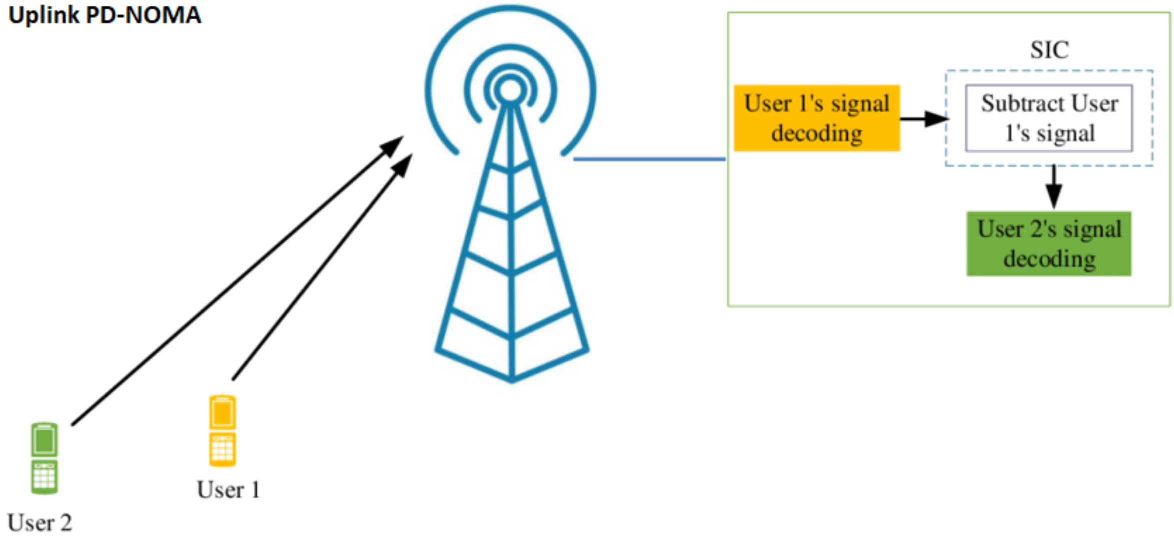

Figure 2.2: Uplink PD-NOMA
[20]

2.5.3 Sequential Power Allocation (SePA) Algorithm

The research work [41] proposed the idea of SePA for PD-NOMA in downlink transmission by keeping the channel gain difference maintained and for analysis author considered distance between users and total number of users by utilizing same bandwidth to transmit data/information and to decode the information SIC is used. At the end it was analyzed that proposed technique performs better as compared to OMA.The total rate and ideal user count in PD-NOMA for every SePA are displayed in the simulation results.

2.5.4 Novel Pilot-Aided Channel Estimation

In literature [37] authors proposed a solution to estimate the channel by using pre-equalized filter.This scheme was also used in OFDM. To support large number of users authors utilized NOMA scheme which also gave the advantage of low latency transmission but BER was degraded.This all was done under fading channels.

2.6 Code Domain NOMA Scheme

As it is mentioned above that CD-NOMA is a type of Multiple Access scheme and it has many advantages. One on the main advantage is that it performs better in

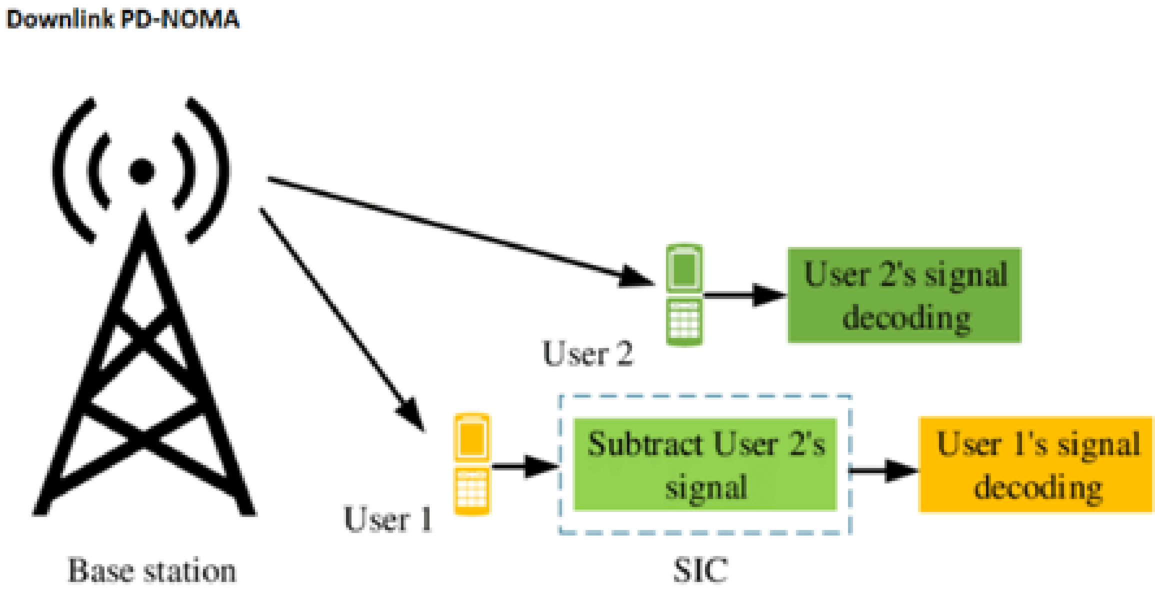

Figure 2.3: Downlink PD-NOMA
[45]

the presence of noise. Unlike CDMA, CD-NOMA spreading sequences are orthogonal to each other which gives us the advantage of accommodating more users.To reduce complexity and enhance the spectral efficiency it is really important that how we design the algorithm [39].

2.6.1 Performance analysis of CD-NOMA in 5G communication system

In literature [8] it is mentioned that OMA technique is not efficient enough to carry massive number of users for future wireless communication in 5G and beyond. So author proposed CD-NOMA as a valid idea to support 5G communication system.Different types of CD-NOMA are discussed in this literature and author compared or analyzed three types of CD-NOMA scheme i.e LDS-CDMA, LDS-OFDMA and SCMA in the presence of AWGN.

2.6.2 Multiple Access with Low-Density Signatures

In [40] author proposed a sequence of low density which means that spreading sequence contains many zero elements and few non-zero elements and this sparsity leads to create more code words for users to transmit signals and analysis is done in presence of AWGN channels.

2.6.3 Multiuser Detection of Sparsely spread CDMA

In research paper [15] CDMA with sparse spreading sequences, with multiuser detection to decode data using belief propagation (BP) with low-complexity is discussed. The strategy is partially motivated by the effectiveness of iterative decoding approach and low-density parity-check (LDPC) codes for transmission of signals. More specifically, a special benefit of sparsely spread CDMA systems is demonstrated. It is demonstrated in many realistic scenarios that BP-based detection gives excellent performance in the huge system. Furthermore, it is demonstrated a fixed-point equation can be used to calculate the degradation factor, referred to as the multi-user efficiency.

2.6.4 Low Density Signature OFDMA for the Uplink

LDS-OFDMA is discussed in [32] for up-link system and it is compared with different multiple access techniques. LDS-OFDMA is a special case of MC-CDMA. It consist of low density spreading sequence which means data symbols are spread over limited number of chips.For decoding MPA is used to get confident and reliable data. BER is compared and analyzed with advance multiple access techniques.

2.6.5 Low-complexity LDS-CDMA Detection

Current LDS-CDMA technique is complex and does not give complete channel information to overcome this problem. LDS-CDMA in [7] is introduced with low complexity for multiple users with dynamic factor graph with compromise in BER.

2.6.6 First-Order Gaussian approximated Algorithm

A technique based on Gaussian approximation (FO-GAA) was introduced by the author in the literature [12] to decrease complexity and enhance BER performance in SCMA when compared to MPA.

2.6.7 Contention-Based SCMA in mMTC

Author in [9] has proposed contention based SCMA in large networks and obtained closed form formulas for the probability of success and the area spectral efficiency. Comparision of contention based SCMA with OFDMA is also done but the limitation is that performance of OFDMA degrades due to increment in number of users. As OFDMA does not support massive connectivity.

2.7 Sparse Code Multiple Access (SCMA)

SCMA is a type of CD-NOMA which was developed by merging multi-dimensional modulation and low-density spreading technique [42] for future machine type communication. This shows that it is a better version of CD-NOMA as compared to LDS-CDMA and LDS-OFDMA as it supports large number of users to utilize the available resources in such a way that they do interfere with each other and enhance the spectral efficiency according to the system requirement. SCMA technique use codebooks [30].

2.8 Data Transmission in SCMA

2.8.1 SCMA Encoding

The entering bits or symbols are directly mapped to sparse code words that are taken from predefined codebooks in order to send data on the transmitter side. Per the literature [47], a single user is assigned to each codebook. Figure 2.4 displays an illustration of six SCMA users. Let us consider an uplink synchronous SCMA system in which data is sent to the basestation (BTS) by J users using K resource components. As an example, j^{th} wishes to send v_j bits. These v_j bits will be mapped by the encoder to a codeword n_j chosen from a predefined codebook CB_j, as indicated below:

$$n_j = CB_j(v_j) \tag{2.4}$$

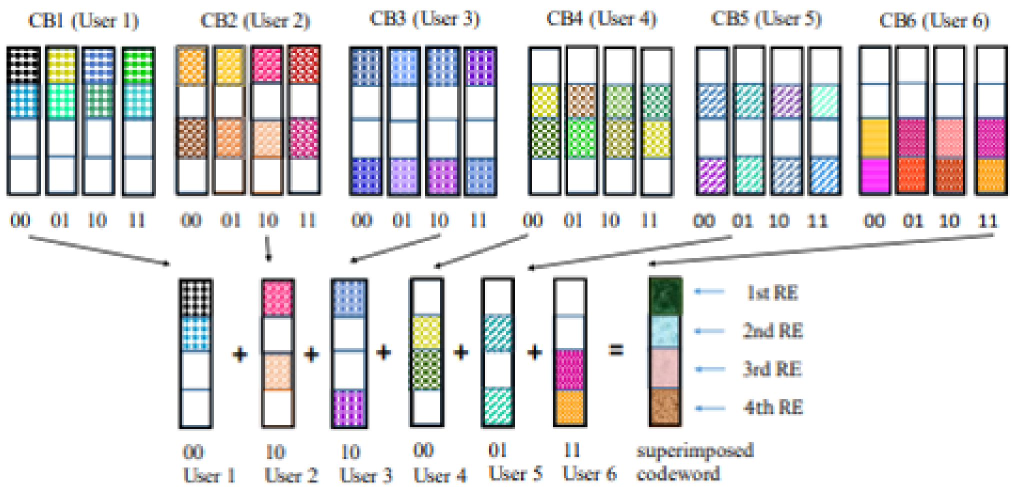

Figure 2.4: An illustration of 4×6 SCMA Encoding [3]

In this case, per user equals per layer. A significant contributing aspect to SCMA's superior performance over other NOMA techniques is its carefully constructed sparse codebooks. Each user has a different sparsity pattern in their codebook, which can be represented as a K×N matrix, where N is the number of codewords (or columns of a CB matrix) that are given to them. Each column vector (codeword) in a CB of each user is sparse and has d_v non-zero entries for that particular user. Multi-dimensional codebooks can be stated as follows for the j^{th} user:

$$CB_j = D_j \Delta_j A_{MC}, \quad \text{for } j = 1, 2, \ldots, J. \tag{2.5}$$

where the binary mapping matrix is denoted by $D_j\ \varepsilon V^{Kdv}$, the multi-dimensional mother constellation is indicated by A_{MC}, and the constellation operator for the jth user is shown by Δ_j. The reason for each user transmitting data over a limited number of resource elements is due to the selection of the mapping matrix. The signature matrix can be used to illustrate allocation of resource elements among users E = [e1, e2, · · · , eJ]. In this case, user j has active transmission across the k^{th} RE, as shown by $E_{jk} = 1$. Given a (4,6) SCMA block with K = 4 REs and J = 6 users, the following is an example of a 4 × 6 signature matrix:

$$E_{4\times6} = \begin{bmatrix} 1 & 1 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 1 & 1 & 0 \\ 0 & 1 & 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 \end{bmatrix} \tag{2.6}$$

The binary mapping matrices corresponding to the six users are given below

$$D_1 = \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 0 & 0 \\ 0 & 0 \end{bmatrix}, \quad D_2 = \begin{bmatrix} 1 & 0 \\ 0 & 0 \\ 0 & 1 \\ 0 & 0 \end{bmatrix}, \quad D_3 = \begin{bmatrix} 1 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 1 \end{bmatrix},$$

$$D_4 = \begin{bmatrix} 0 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 0 \end{bmatrix}, \quad D_5 = \begin{bmatrix} 0 & 0 \\ 1 & 0 \\ 0 & 0 \\ 0 & 1 \end{bmatrix}, \quad D_6 = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 1 & 0 \\ 0 & 1 \end{bmatrix}.$$

D1 indicates that user 1's data are transmitted over the first, and the second REs. Similarly, D2 represents that user 2's data are transmitted over the first and the third REs, and so on.Once the mapping matrices are decided, one also requires mother constellation A_{MC} and layer-specific operations, Δ_j .

Once the mother constellation is decided,the implementation of layer-specific operations are applied so that multiple to create different code books for different users. These operations may include phase rotation, complex conjugate, layer power offset, and dimensional permutation [3]. The received signal at the ith user can be expressed as

$$y_i = (y_{i1}, \ldots, y_{iK})$$

2.8.2 Message Passing Algorithm for SCMA Decoding

For a SCMA system, let h_i be the channel gain for the j^{th} user, n_j be the transmitted codeword. The received signal at the Base station is

$$y = \sum_{j=1}^{J} \text{diag}(\mathbf{h}_i)\mathbf{n}_j + \mathbf{w}_i \tag{2.7}$$

where w_i is the Additive White Gaussian Noise which is distributed as $CN[0, \sigma^2]$ [3].To decode the information at the receiver side MUD algorithm is used i.e Message Passing Algorithm [18]. It decodes the data with acceptable complexity. MPA uses factor graph. The algorithm works in two steps i.e it updates the belief associated message and passes the extrinsic information between the layer nodes and resource nodes.

The figure 2.5 shows J layers over K resources [30] and represents the factor graph of MPA.

2.9 Hybrid PD-NOMA and SCMA Schemes

One promising technology for reaching the best spectrum sharing for next heterogeneous networks is hybrid multiple access.It not only a new technology for communication system but it is also the requirement of the users as per their demand. To fulfill the demands of users keeping future demands in mind, hybrid scheme is considered as it will take the advantages of two separate schemes and it will combine to perform very efficiently.

2.9.1 Hybrid NOMA technique for Down-link Transmission

In literature [35] hybrid scheme is used for Downlink in 5G and Beyond in which users experience diverse channel condition, analysis and comparison was done with conventional PD-NOMA and SCMA scheme in presence of AWGN and both AWGN and Rayleigh Fading channel. System performance was designed in such a way that there were two SCMA groups and they were assigned different two codebooks. SCMA

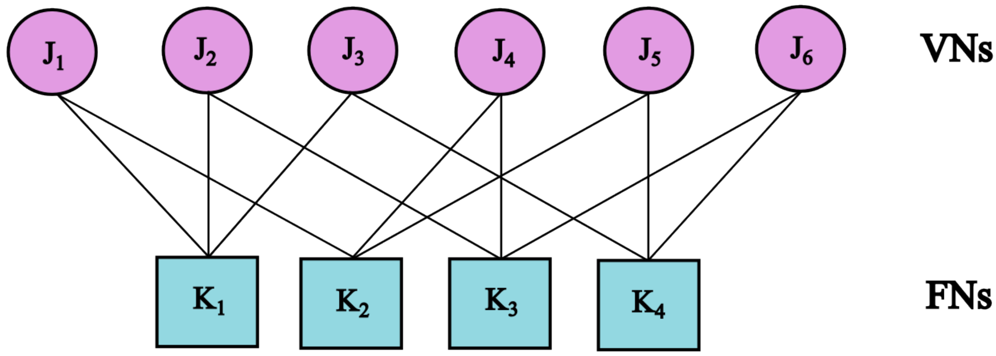

Figure 2.5: Factor Graph Representation of SCMA,with K=4 and J=6

encoding was done to transmit the data and for detection MPA and SIC was applied. The figure 2.6 shows the proposed model discussed in [35]

Results shows joint schemes performs better. Message Passing Algorithm Dectector (MPAD) based SIC is used.But the limitation of this paper was spectral efficiency is not analyzed for massive connectivity.Complexity has increased.

2.9.2 Hybrid NOMA technique for Up-link Transmission

In [43] hybrid scheme of SCMA and PD-NOMA supports large number of up-link users for future 5G network.Comparison of proposed scheme with multi-antenna SCMA and multi-antenna PD-NOMA.Power allocation design are formulated that maximizes the sum rate of entire system(proves hybrid schemes shows better results) but the research gap is over loading factor for all three systems is the same i.e 1 and complexity increases by applying SCMA to all groups to encode data and data is superimposed by PD-NOMA.

2.9.3 Joint Up-link NOMA scheme for Future

In the proposed system [13] superposition coding is done for two groups, in which available resources is shared among all 2J users non-orthogonally. Same codebook is

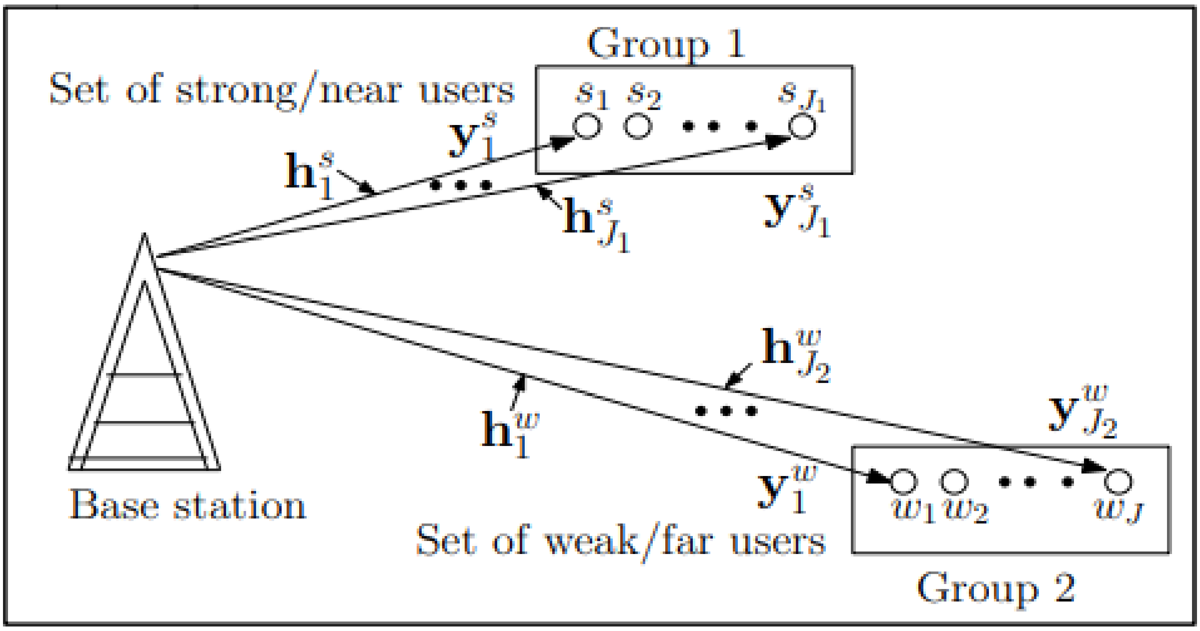

Figure 2.6: Joint hybrid downlink scheme strong/near SCMA users [35]

utilized by all the users. SIC and MPA are combined at the receiver to decode the information. The drawback of this scheme is complexity has increased due to the overlapping of factor graph but SE has improved as compared to conventional SCMA scheme.

2.9.4 Hybrid MIMO NOMA scheme Up-link Transceiver

In literature [4] Expectation Propogation Algorithm(EPA) and SIC is applied in which system capacity and BER is guaranteed with increased number of antennas. The research gap of this literature is performance degrades when number of layers are increased as interference is aggravated and EPA performance is limited for large codebook size and massive MIMO applications. Small cell user (SUs) and macro cell user (MUs) which are multiplexed on a codebook are investigated, together with pairing and power capacity constraints.

2.9.5 Hybrid PD-NOMA and SCMA scheme for Resource Allocation

Combination of two techniques is proposed in paper [16] called PSMA for 5G cellular systm to support large number of user,to improve SE and to reduce complexity.Here encoded signals are simultaneously sent over a set of sub-carriers or frequencies resource elements by using joint schemes of MA. All users utilize the same codebook and signals are delivered non-orthogonal manner. When codebook is shared by more than one user then inter-cell interference occurs between users. In particular, the PSMA system's receiver component has been used, with the primary goal being to solve the bi-pirate graph. The accuracy of the decoding was increased and spectral usage is increased by primary analysis.

Chapter 3

Proposed Model

3.1 System Model

This study investigates a down-link hybrid PD-NOMA and SCMA approach tailored for massive Machine Type Communication (mMTC), accommodating a variable number of users denoted. The system is organized into three user groups positioned at varying distances from the base station.

The first group, denoted as PD-NOMA-1, consists of four users located farthest from the base station. Similarly, the second group, labeled PD-NOMA-2, comprises four PD-NOMA users situated at an intermediate distance from the base station. Lastly, the third group, comprising six SCMA users, is positioned nearest to the base station.

By organizing users into distinct groups based on their proximity to the base station, this hybrid PD-NOMA and SCMA scheme aims to optimize communication performance and spectral efficiency in mMTC scenarios. This approach addresses the unique challenges posed by varying user distributions and enables efficient resource allocation to maximize system capacity and reliability,as shown in figure 3.1.

According to PD-NOMA [19] unique power ranks are assigned to different users according to their distances from base station and their channel condition. Only one antenna at the base station (BS) is used to transmit data to all the users. Each user is equipped with one receiving antenna. The BS can serve users using the same time/code/frequency but with unique power ranks. Highest power rank is assigned to PD-NOMA-1 users as it is most far away from the base station and it has poor channel condition,medium power rank is assigned to PD-NOMA-2 users and lowest power rank is assigned to SCMA users as it is nearest to base station and it has good channel condition.
For PD-NOMA users Quadrature Phase Shift Keing QPSK modulation is used because it carry twice as much information as ordinary PSK using the same Band Width (BW) and for SCMA users symbol mapping is done for encoding. Data for PD-NOMA and

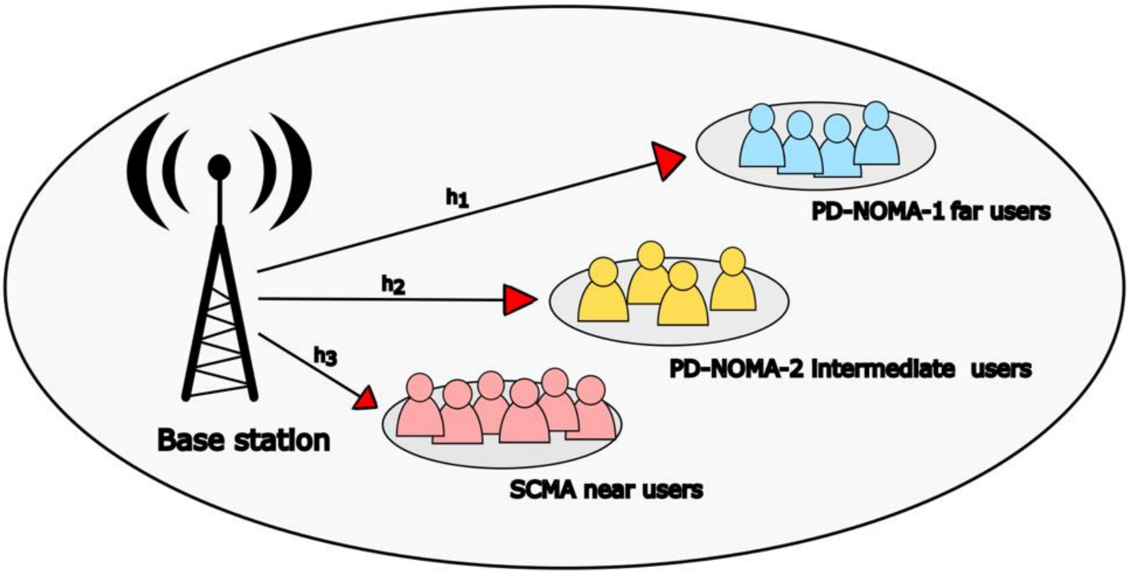

Figure 3.1: System Model

SCMA users is send under AWGN channel. In SCMA, the signals of J users are transmitted over K resources or sub-channels will be referred to as the J×K SCMA system.Each user is assigned a codebook.Each codeword of a codebook has non-zero complex components which shows sparsity . The $\log_2 V$ data bits are directly mapped to the K-dimensional codeword for the transmission. Further, the system overloading factor is expressed as $\lambda = J/K$.

3.2 Transmitter Side

3.2.1 Superposition Coding

Several users are multiplexed on a single resource unit in both domains(power-domain and code-domain) in the proposed hybrid power domain sparse code non-orthogonal multiple access (PD-SCMA) system. The proposed method superimpose extra users having different quality of service requirements, on the SCMA multiplexed signal in a spectrally efficient manner.The extra users will be accommodated in the existing

SCMA resources using different power ranks and modulation allowing all J users to share K orthogonal radio resources simultaneously.A combined signal X is sent by a transmitter i.e BS and after superposition coding is applied to transmit the signal to the users of three groups:

$$X = \sum_{i=1}^{4} \sqrt{P\beta_i} S_i + \sum_{k=1}^{4} \sqrt{P\beta_i} S_i + \sum_{j=1}^{6} \sqrt{P\beta_i} S_i \quad (3.1)$$

In the superposition encoding phase,it maps the respective input bits to three output bit sequences S_1, S_2 and S_3 for PD-NOMA-1 and PD-NOMA-2 and SCMA users respectively,where β_i represents a fraction of the total power P assigned to the group of users and i={1,2,3...,N},subject to the constraint on $\beta1 + \beta2 + \beta3 = 1$. Here k={1,2,3...,N}, j={1,2,3...,N}.

3.2.2 Block Diagram

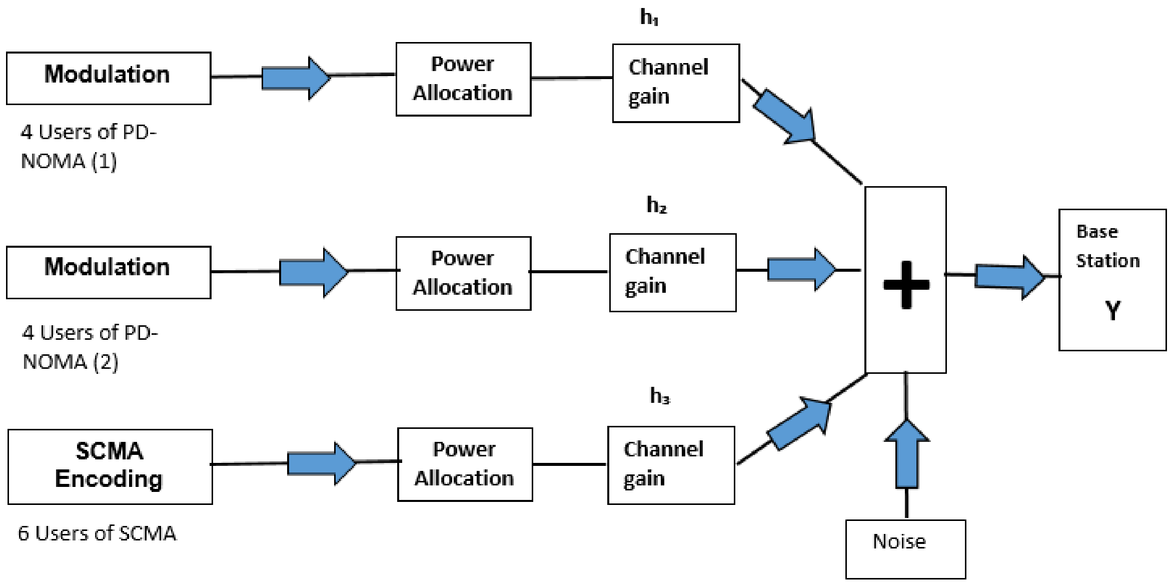

Figure 3.2: Transmitter Design

3.3 Receiver Side

The received signals of three groups are:

$$y_1 = h_1 x + w_1 \tag{3.2}$$

$$y_2 = h_2 x + w_2 \tag{3.3}$$

$$y_3 = \text{diag}(h_3) x + w_3 \tag{3.4}$$

where :
•y_1 is the received signal of PD-NOMA-1 users
•y_2 is the received signal of PD-NOMA-2 users
•y_3 is the received signal of SCMA users
•w_1, w_2 and w_3 is the Additive White Gaussian Noise
•h_1, h_2 and h_3 are the channel gains which are multiplied with the combined signal x. Here, channels are sorted as

$$0 < |h_1| \leq |h_2| \leq |h_3|$$

which indicated that far users will always hold weakest channel.

3.3.1 SIC and MPA

According to proposed receiver design, received signal at PD-NOMA-1 given in equation (3.2),direct detect and decoding is applied on it as it far away from the base station,highest power rank is given to it and it has poor channel condition.To decode the data of PD-NOMA-2 users SIC is applied on received signal given in equation (3.3) . To decode the received signal of SCMA users given in equation (3.4) SIC is applied to remove the signal of PD-NOMA-1 users after that SIC is again applied to remove the PD-NOMA-2 users signal and at the end MPA is applied. The SCMA system is taken into consideration in the proposed system (4,6) with N = 4, meaning that each codebook contains four codewords that are mapped to two binary bits ,where J users communicate over K resource elements (REs),as shown in figure 2.4 which corresponds to the signature matrix $E_{4\times6}$ given in equation 2.8.1. Note that the number of users superimposing over one RE is 3, i.e., $d_f = 3$ and the number of non-zero values in a column is 2, i.e., $d_v = 2$. The received signal at the k^{th} RE is given below. The equation is given by:

$$y_k = h_{k1} C_{k,1}(n_1) + h_{k2} C_{k,2}(n_2) + h_{k3} C_{k,3}(n_3) + w_k, \tag{3.5}$$

where k =1,2,3,....,K where n1, n2, n3 are the codewords of users which belong to set ξ_k. From $E_{4\times6}$, the set of users which interfere over the first RE is $\varrho_1 = \{1, 2, 3\}$. and the set of REs at which the first user has active transmission is $\varsigma_1 = \{1, 2\}$ and so on. Let the set of users sending data via the kth RE be represented by ϱ_k. and ς_j be the set of REs on which the jth user has active transmission, respectively. By definition, the numbers of elements in ϱ_k and ς_j are d_f and d_v, respectively.

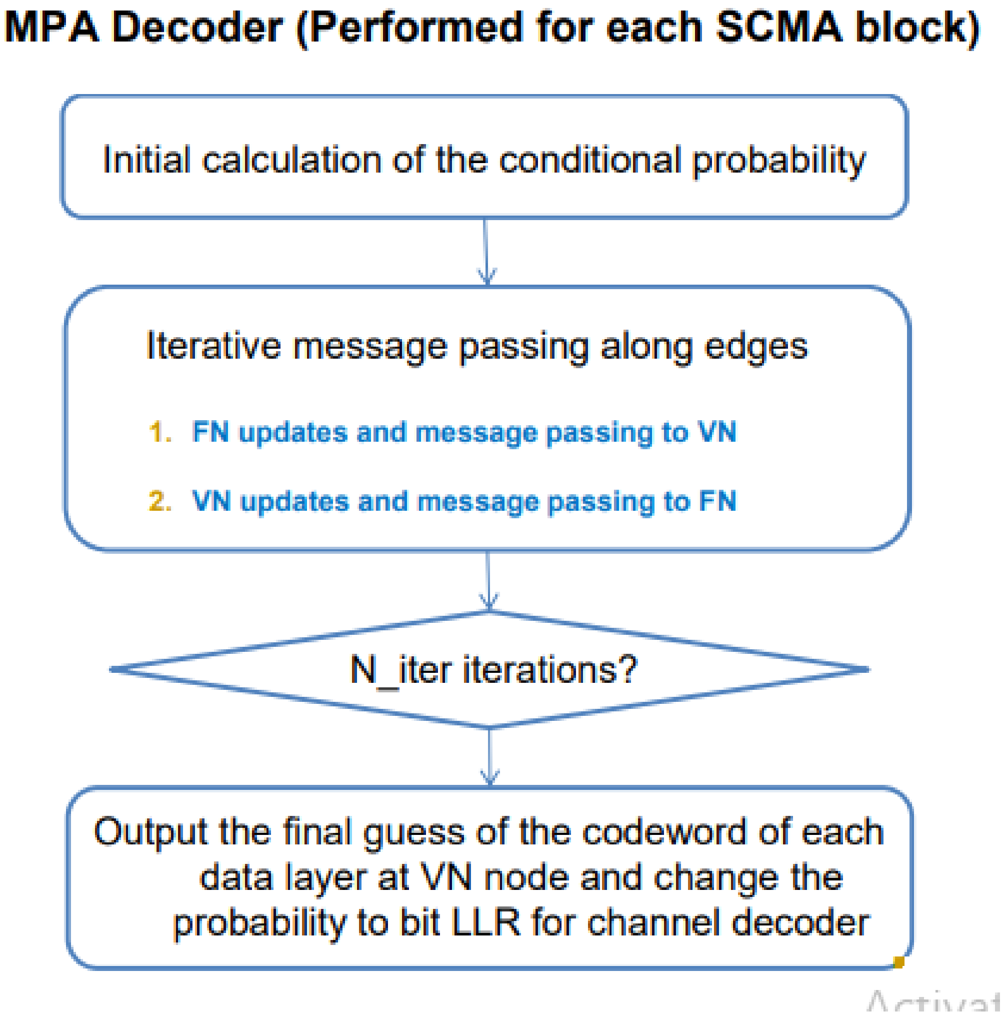

Figure 3.3: Flowchart of MPA decoder

The objective is to detect and decode the data accurately with reduced complexity transmitted by each user and this can be carried out in the following steps as shown in figure3.3.To improve the detection performance reliability of each value (sent by transmitter)is computed by using Baye's Rule:

$$P(c_1 = 0|y_1) = \frac{f(y_1|c_1 = 0) \cdot P(c_1 = 0)}{f(y_1)} \tag{3.6}$$

$$P(c_1 = 1|y_1) = \frac{f(y_1|c_1 = 1) \cdot P(c_1 = 1)}{f(y_1)} \tag{3.7}$$

For binary variables, the output vector is formed by three log-likelihood ratios (LLRs) [L_1, L_2, L_3] which are all real values indicating the 'confidence or reliability level' that for example the bit is 0. Then guess the output for each variable node VN node (for each data layer) as the detection results after 15 iterations. The guess at variable node VN node v for codeword n is a chain product of all

$$I_v(n_v) = P_a(n_v) m_{l_1 \to v}(n_v) m_{l_2 \to v}(n_v) \quad \text{for } n_v \in A_v$$

guesses from all its neighboring FN nodes and the a prior probability.Where 'g' is extrinsic information sent from function node to variable node v and vice versa,as shown in figure below.

After getting the probability guess of codeword at each layer, we then need to calculate the Log-Likelihood-Rate (LLR) with is represented as Q here for each coded bit directly after MPA. The first and second bit of the symbol's LLR i.e Q is

$$\mathrm{Q}_{v,b_1} = \max_{n_1^v, n_2^v} \left(\log(I_v(n_1^v) + I_v(n_2^v)) - \max_{n_3^v, n_4^v} (\log(I_v(n_3^v) + I_v(n_4^v))) \right)$$

$$\mathrm{Q}_{v,b_2} = \max_{n_1^v, n_3^v} \left(\log(I_v(n_1^v) + I_v(n_3^v)) - \max_{n_2^v, n_4^v} (\log(I_v(n_2^v) + I_v(n_4^v))) \right)$$

If $\mathrm{Q}_{v,b_1} < 0$, then it is decoded as 1 for the first bit of the symbol otherwise 0. Similar is the case for Q for the second bit. Hence,we can decode the transmitted information or data correctly by applying proposed algorithm given above.

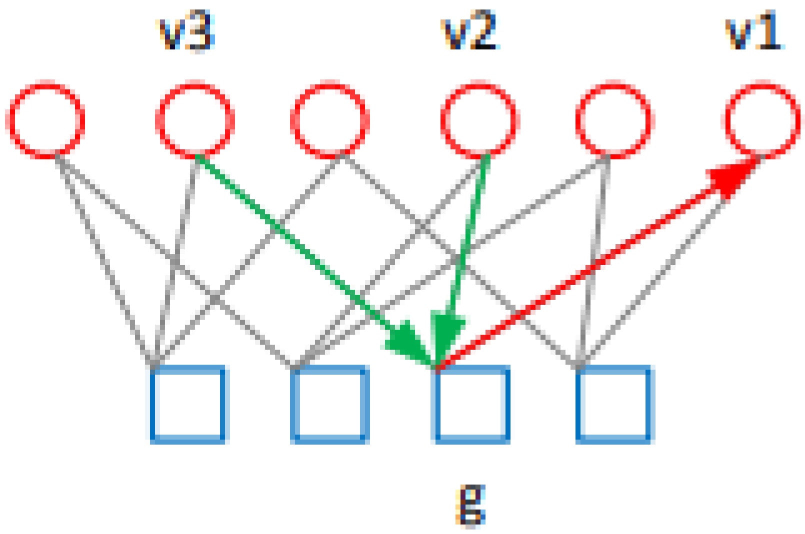

Figure 3.4: Data flow from VN to FN and FN to VN

3.3.2 Block Diagram

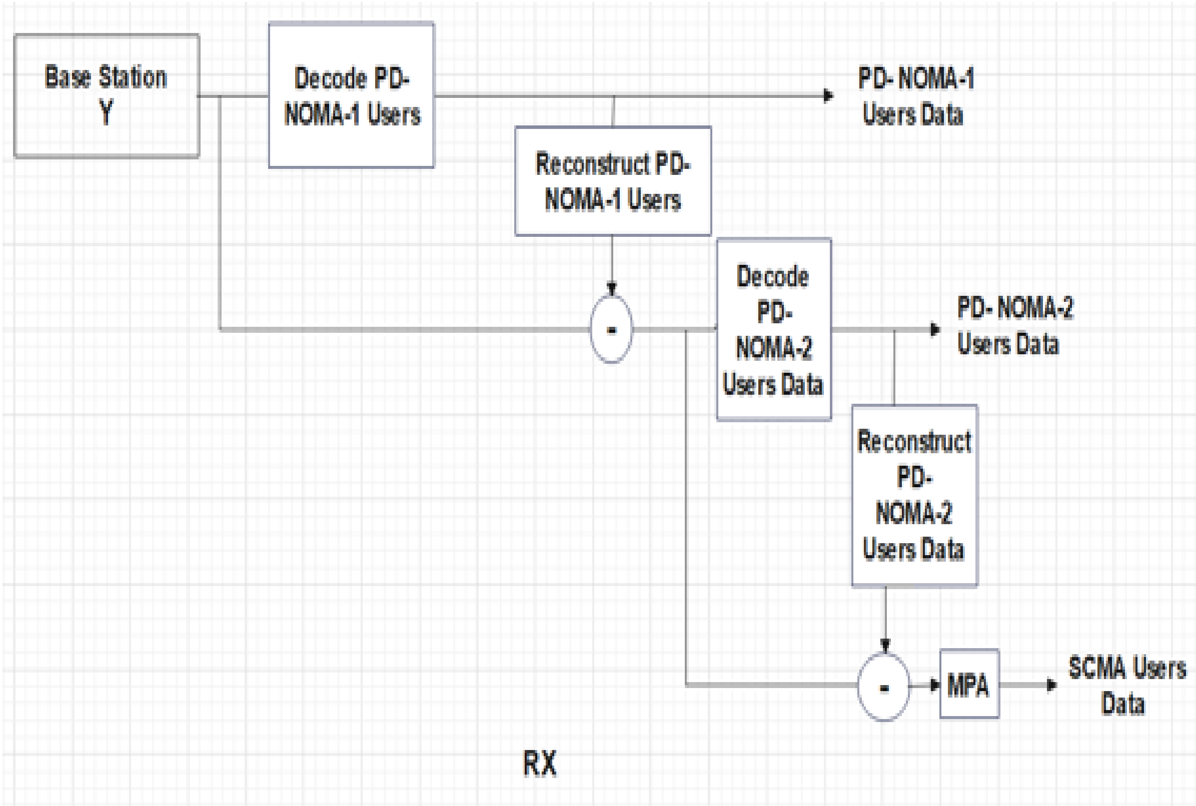

Figure 3.5: Receiver Design

Chapter 4

Results and Simulations

In this chapter of research work, the results of proposed Hybrid scheme of Power-Domain Non-Orthogonal Multiple Access (PD-NOMA) and SCMA for mMTC scheme are given.

In the first scenario, two PD-NOMA users are analyzed, each positioned at unique distances from the base station and unique power ranks are assigned based on their respective channel conditions. The communication channel is considered as an Additive White Gaussian Noise (AWGN) channel.

User 1, situated farther from the base station at a distance of d1=100 with power rank of p1=0.75. Conversely, User 2, located nearer to the base station at a distance of d2=500 with power rank of p2=0.25. The modulation scheme employed for both users is Binary Phase Shift Keying (BPSK).

To evaluate the performance of the system, the Bit Error Rate (BER) is computed. This analysis enables an assessment of the communication reliability and efficiency of the PD-NOMA scheme under varying channel conditions and power ranks.The results for near and far users are shown below in figure 4.1
SCMA achieves high spectral efficiency by facilitating the simultaneous sharing of resources among multiple users through the utilization of sparse non-orthogonal codebooks. This capability optimally utilizes the available bandwidth, enhancing overall system performance.

In the second scenario, the performance of SCMA is evaluated under standard parameters: J=6, K=4, d_f=3, d_v=4, and N=4, within an Additive White Gaussian Noise (AWGN) channel environment. The system is configured with an overloading factor denoted as λ, calculated as the ratio of J to K, set to 1.5. The codebook design follows the methodology proposed in [3].

Performance evaluation involves calculating the Bit Error Rate (BER) to assess the effectiveness of the SCMA scheme under these conditions. This analysis provides insights into the reliability and efficiency of SCMA in practical communication scenarios,

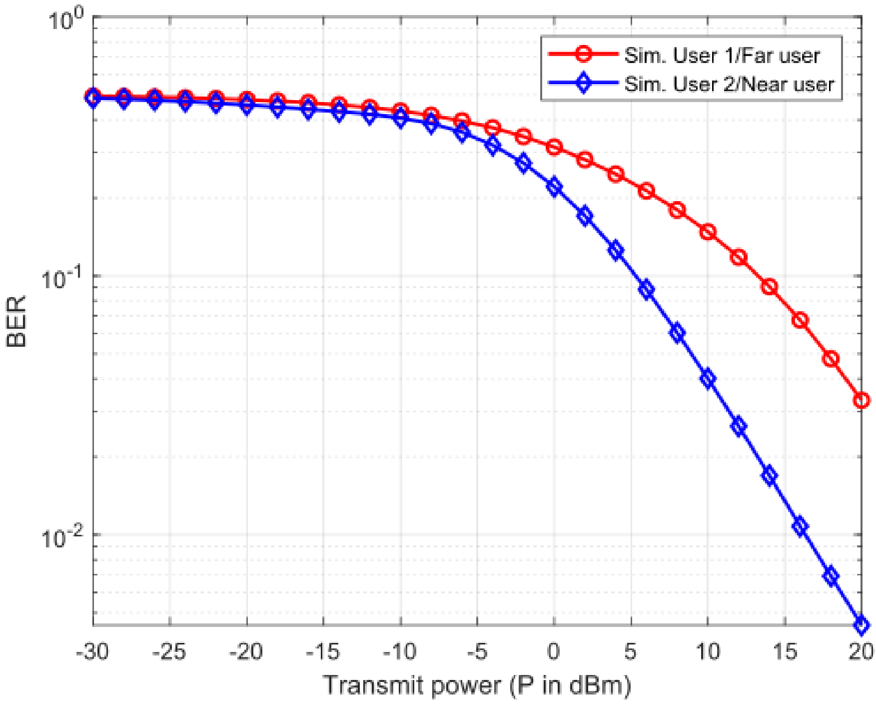

Figure 4.1: BER performance of conventional PD-NOMA users(near,far)

highlighting its potential for enhancing spectral efficiency and accommodating multiple users within a shared resource framework. The results are given below in figure 4.2 In the third scenario, a hybrid scheme is employed with two distinct user groups located at varying distances from the base station (BS). One group comprises 4 users utilizing PD-NOMA, while the other consists of 6 users employing SCMA.

The PD-NOMA user group, positioned farther from the BS at a distance of d1= 100 with power rank of p1= 0.9 and utilizes Quadrature Phase Shift Keying (QPSK) modulation. On the other hand, the SCMA user group, situated closer to the BS at a distance of d2=400 with power rank of p2= 0.1 under an Additive White Gaussian Noise (AWGN) channel. Additionally, a codebook is assigned to the SCMA users.

The overloading factor, denoted as λ, is increased to 2.5, indicating an enhanced capacity to accommodate more users in the system. This demonstrates that the hy-

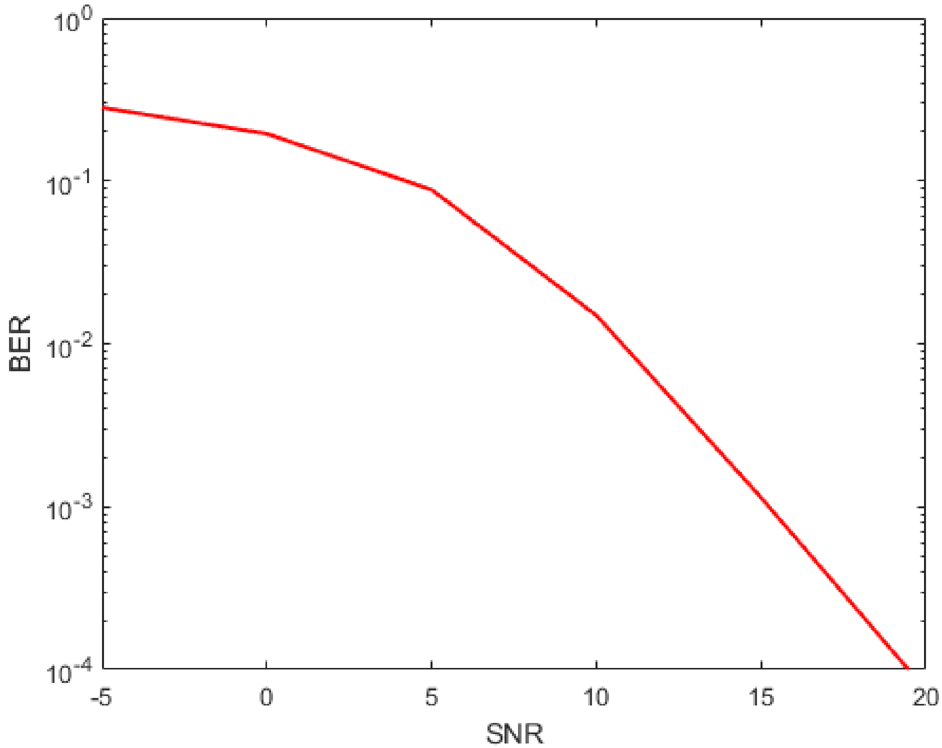

Figure 4.2: BER performance of conventional SCMA with K=4 and J=6

brid scheme outperforms conventional PD-NOMA or SCMA approaches in supporting massive connectivity.

Moreover, while the hybrid scheme exhibits improved performance compared to individual PD-NOMA or SCMA schemes, it is noted that the Bit Error Rate (BER) also increases in the hybrid setup. This observation underscores the trade-offs involved in optimizing system performance for massive connectivity scenarios. The BER performance for hybrid scheme with two groups of users is given below in figure 4.3

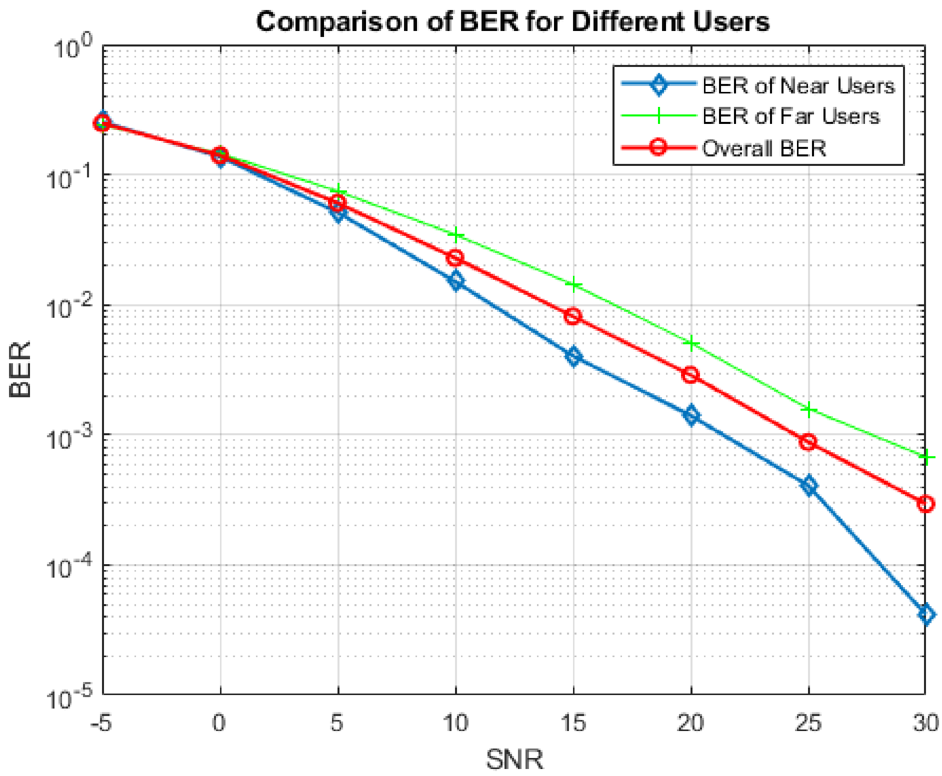

Figure 4.3: Hybrid PD-NOMA and SCMA scheme BER performance(2 groups of users)

Table 4.1. Hybrid PD-NOMA and SCMA with 2 groups of users

Parameters	**Specifications**
Techniques used	NOMA
Schemes used	PD-NOMA, SCMA
Channel	AWGN channel
Noise	Additive White Gaussian Noise
Modulation	QPSK
Distance (D1, D2)	1000, 400
Power Rank (p1, p2)	0.9, 0.1
SNR	-5 to 30 dB

In the fourth scenario, a novel downlink hybrid PD-NOMA and SCMA scheme is analyzed for massive Machine Type Communication (mMTC). The users are categorized into three groups based on their distances from the Base Station (BS).

The PD-NOMA-1 group consists of 4 users located far from the BS at a distance of 1000 units (denoted as d1), with a power rank of p1=0.8. The PD-NOMA-2 group comprises 4 users at an intermediate distance from the BS (d2= 600) with a power rank of p2= 0.18. The SCMA group comprises 6 users located near the BS (d3= 200) with a power rank of p3= 0.02. Additionally, additive white Gaussian noise (AWGN) and AWGN channel is considered in the system .

The modulation scheme employed for the PD-NOMA groups is Quadrature Phase Shift Keying (QPSK), while a codebook is assigned to the SCMA users. The overloading factor λ has increased to 3.5, compared to 1.5 in conventional SCMA techniques.

Performance analysis is conducted to evaluate the Bit Error Rate (BER) for the PD-NOMA-1 (far users), PD-NOMA-2 (intermediate users), and SCMA (near users). Furthermore, the overall BER is analyzed for all users. Results demonstrate that the proposed hybrid scheme outperforms both conventional PD-NOMA and SCMA schemes and it is also showing better BER as compared to hybrid scheme mentioned above with 2 groups of users.

This novel approach offers improved SE, overloading factor and reduced complexity, making it a promising solution for mMTC scenarios characterized by diverse user distributions and quality-of-service requirements.Results are shown in figure 4.4.

Table 4.2. Hybrid PD-NOMA and SCMA with 3 groups of users

Parameters	**Specifications**
Techniques used	NOMA
Schemes used	PD-NOMA, SCMA
Channel	AWGN channel
Noise	Additive White Gaussian Noise
Modulation	QPSK
Distance (D1, D2,D3)	1000, 600,200
Power Rank (p1, p2,p3)	0.8, 0.18,0.02
SNR	-5 to 40 dB

The overall BER for comparison between PD-NOMA 2 users, SCMA with 6 users, Hybrid PD-NOMA and SCMA with 10 users and proposed hybrid scheme with 14 users are given in figure 4.5.We can see that see that inspite of being highly overloaded proposed hybrid scheme occupies more SNR which means signal is better as compared to SCMA with 6 users and it can accomodate more users.Whereas in comparison to PD-NOMA scheme with 2 users proposed hybrid scheme BER has degraded due to complexity has increased to accomodate large number of users.

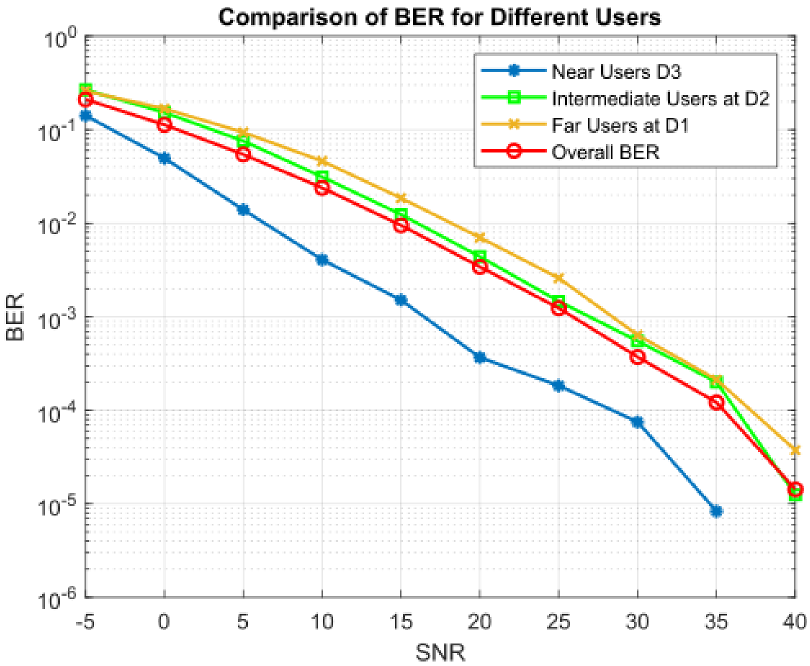

Figure 4.4: Proposed Hybrid Scheme BER with three group of users

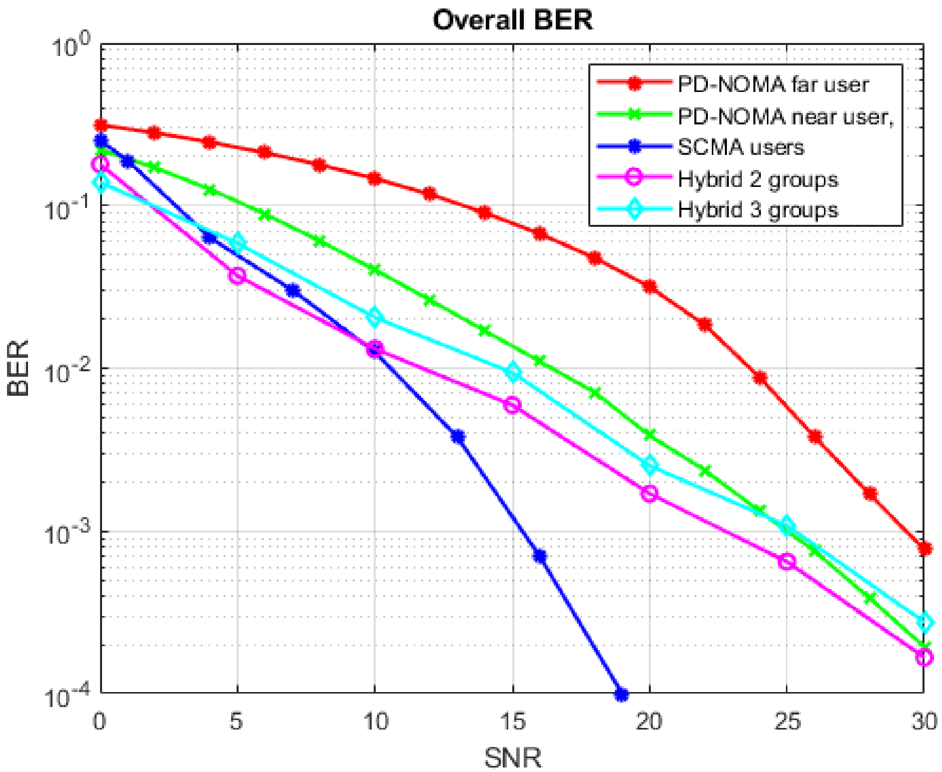

Figure 4.5: Proposed Hybrid Scheme BER with three group of users

Chapter 5

Conclusion and Future work

5.1 Conclusion

From the results and simulations given in previous chapter it is proved Hybrid scheme of PD-NOMA and SCMA is a promising technique for 5G and beyond wireless communication. In this work, an in-depth analysis of down-link hybrid power domain NOMA and SCMA for mMTC is discussed. Proposed scheme analysis is done considering AWGN channel, QPSK modulation scheme and Additive White Gaussian Noise .Three groups of 14 users at different distances with different power ranks are considered. 2 groups of users are considered as PD-NOMA users and one group is considered as SCMA users.
Superposition coding is applied to transmit the data from Base station to three different groups of users and SCMA symbol mapping is done at the transmitter side for SCMA users with power multiplexing.
To decode the transmitted data direct detect and decoding is applied on farthest users of PD-NOMA-1 as it has highest power rank.Successive Interference Cancellation (SIC) is applied on intermediate users of PD-NOMA-2 with intermediate power rank and considering farthest users data as noise,it cancels the signal of farthest users to decode its own signal.To decode the nearest group of SCMA, SIC is applied two times,first to cancel the farthest signal of PD-NOMA-1 users and then to cancel intermediate signal of PD-NOMA-2 users.Then it decodes it own signal.At the end Message Passing Algorithm (MPA) on SCMA users at the receiver side is applied to decode with non-complex algorithm. It has been observed that, in spite of being highly overloaded, the performance of the proposed scheme shows SE has improved from 12 bps/Hertz of conventional SCMA scheme with 6 users to 28bps/Hertz in proposed hybrid scheme,complexity in algorithm has decreased and overloading factor has increased from 1.5 to 3.5.

5.2 Future Work

Explore methods to integrate PD-NOMA and SCMA for improved spectral efficiency and reliability in wireless communication systems.The design and implementation of optimal CB remains an open challenge for all researchers. The current designs are most likely sub-optimal.Apply machine learning techniques to upgrade the performance of NOMA and SCMA systems. This includes using machine learning for user grouping, power allocation, and codebook design.Investigate the security challenges associated with hybrid power domain PD-NOMA and SCMA to keep data safe.

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