KADIR HAS UNIVERSITY
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SCMA CODEBOOK DESIGN APPROACHES

FURKAN KIRACI

MASTER’S THESIS

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MASTER'S THESIS

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This work entitled **SCMA CODEBOOK DESIGN APPROACHES** prepared by **FURKAN KIRACI** has been judged to be successful at the defense exam held on **07.02.2020** and accepted by our jury as **MASTER'S THESIS**.

APPROVED on:

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SCMA CODEBOOK DESIGN APPROACHES

ABSTRACT

In 4G systems, Orthogonal Frequency-Division Multiple Access (OFDMA) has been used conventionally for multiple access purposes. This technique has low spectral efficiency since it allocates the resources orthogonally to each user. As an alternative to this technique, Non-orthogonal Multiple Access (NOMA) has been proposed for new generation 5G systems as it allows different users to use the same resources and therefore, increases spectral efficiency. Sparse Code Multiple Access (SCMA) is a code-based NOMA technique and its performance depends on codebook design. In this thesis, four different approaches are proposed by examining the design of the conventional codebook, which is widely used in SCMA studies in the literature. In the first approach, the distances between the constellation set points have been increased while the total energy remains constant. In the second approach, the angle between the constellation set points on the sub-carriers in the codebook has been equally set. In the third approach, by applying the permutation method, it has been aimed to reduce the complexity in the codebook by multiplying the constellation set points on the first and second sub-carriers with the half-angle formula. In the fourth approach, a new constellation set points with the energy remaining constant has been designed. Considering the four different design approaches, the conventional codebook has been modified. Simulation results have shown that 1-2dB gain can be achieved using different design approaches in the high signal-to-noise-ratio (SNR) region.

Keywords: 5G, OFDMA, NOMA, SCMA, Codebook Design, SNR

SCMA KOD KİTABI TASARIMI YAKLAŞIMLARI

ÖZET

4G sistemleri geleneksel olarak Dikgen Frekans-Bölmeli Çoklu Erişim (Orthogonal Frequency-Division Multiple Access, OFDMA) tekniğini kullanırlar. Bu yöntemde her kullanıcıya kendisine ait bir kaynak tahsis edildiğinden spektral verimliliği düşüktür. Bu duruma alternatif olarak geliştirilen ve yeni nesil 5G sistemler için düşünülen Dikgen-olmayan Çoklu Erişim (Non-orthogonal Multiple Access, NOMA) tekniği, farklı kullanıcıların aynı kaynakları kullanmasına izin verir ve böylece spektral verimlilik artırılır. NOMA'nın kod tabanlı yaklaşımı olan Seyrek Kodlu Çoklu Erişim (Sparse Code Multiple Access, SCMA) tekniğinin performansı kod kitabı tasarımına bağlıdır. Bu tez çalışmasında, literatürdeki SCMA çalışmalarında yaygın bir şekilde kullanılan geleneksel kod kitabının tasarımı incelenerek dört farklı yaklaşım önerilmiştir. Birinci yaklaşımda enerjsi sabit kalacak şekilde işaret kümesi noktaları arasındaki uzaklıklar artırılmıştır. İkinci yaklaşımda kod kitabındaki alt taşıyıcılarda bulunan işaret kümesi noktaları arasındaki açılar eşit olarak ayarlanmıştır. Üçüncü yaklaşımda permutasyon yöntemi uygulanarak, birinci ve ikinci alt taşıyıcıda bulunan işaret kümesi noktalarını yarım açı formülü ile çarparak kod kitabındaki karmaşıklığın azaltılması hedeflenmiştir. Dördüncü yaklaşımda ise enerjisi sabit kalacak şekilde yeni bir işaret kümesi noktaları tasarımı önerilmiştir. Özetle, dört farklı tasarım yaklaşımı kullanılarak yaygın olarak kullanılan kod kitabı modifiye edilmiştir. Benzetim çalışmaları göstermektedir ki yüksek işaret gürültü oranı (signal-to-noise-ratio, SNR) bölgesinde kullanılan yaklaşıma bağlı olarak 1-2dB'lik kazanç elde edilebilmektedir.

Anahtar Sözcükler: 5G, OFDMA, NOMA, SCMA, Kod Kitabı Tasarımı, SNR

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I would like to thank my thesis advisor Assoc. Prof. Serhat Erkucuk for his knowledge, contributions and guidance during my thesis. Without his assistance, it would be really hard to finish my thesis project.

To my parents

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1.INTRODUCTION

As a result of the rapid improvement of integrated circuit technology in the last two decades, it has caused great changes in all areas from communication systems we have used to all electronic devices (laptop, phone, tablet etc.). Depending on these developments, new generation different concepts (Internet of Things, Big Data Analysis, Artificial Intelligence, etc.) that we have not heard before have entered our lives. A large amount of data traffic is required to apply these concepts. To meet this data traffic effectively, there is a need for a radical change in the communication networks used. Wireless communication networks are among the most important parts of Information and Communication Technology (ICT), which provides infrastructure support to different industries [1]. The development of each generation from the first generation (1G) communication system to the fourth generation (4G) Long Term Evolulation (LTE) has taken about 10 years for each generation, and the fifth generation cellular systems are predicted to be in our lives in 2020s. LTE technology is the communication technology that transmits high speed wireless data, called the continuation of the 4G communication system. The LTE system has more advantages than 4G technology, such as latency, higher user data rates, improved system capacity and coverage, and low operating cost [2]. LTE communication technology can use 2G and 3G technologies as infrastructure. Previous generation mobile communication systems (2G, 3G, 4G) are monolithic as infrastructure, these communication systems are based on the transfer of information from human to human providing restricted number of services for instance SMS, voice service, mobile broad-band [3]. 5G systems, on the other hand, support enhanced mobile broadband (eMBB), massive machine type communications (mMTC) and ultra-reliable and low-latency communications (URLLC), cover a large number of service types, traffic and users, and have met the needs of industries such as automotive, manufacturing and entertainment [4]. The excessive growth of wireless technologies has caused the 5G industry to meet the needs of users for smart technologies in the future [5]. Especially in the automotive sector, studies on 5G technology in new generation vehicles (autonomous) have come to the fore. The use of 5G technology is gaining importance day by day with IoT and deep learning methods in many use cases, from the vehicles communicating with each other to the security area. Millimeter-Wave (mmWave) communication is considered as a suitable approach for 5G vehicle communication systems, equipped with sensors that generate Gbps data for driving experience in future autonomous vehicles [6]. 5G mmWave vehicular communication system involves a smart and stable solution.

With the fast development of technology in last years, 4G LTE networks which are used in the field of telecommunications, do not demand data transfer and communication capacity for the millions of users. To enhance the system performance, some technologies increasing capacity, such as massive multiple-input multiple output (MIMO), Orthogonal Frequency Division Multiplexing (OFDM), cooperative communications and millimeter wave communications etc., have been researched [7], [8], [9], [10]. With the new generation cellular communication technology of 5G, low latency, massive connectivity and better service quality are expected [11]. In this context, the benefits of 5G technology can be summarized as follows:

- Having 100 times more connected devices than current LTE networks today [12]
- 1000 times more capacity
- $1/1000$ power consumption per bit transmission
- 90% lower power consumption per mobile service

The infrastructure of the devices used in the current 4G technology is not suitable for being used in the 5G technology. Therefore, components of communications such as base stations, satellites and frequency bands must have new infrastructure features in accordance with the 5G technology. 5G mobile communication system no longer meets the distribution structure of large base stations. Base stations are smaller in size and will transmit data at a higher speed. These base stations will interfere with each other. New satellite transmission technologies, spectrum usage technologies, receiver/modem and network structures are going to quickly mature and improve in future years [13]. The related frequency bands include the 6-100 GH z frequency band and the low frequency band below 6GHz [14]. There are some points to consider when choosing frequency bands:

- The frequency band must provide cellular network and corresponds to other available networks in same frequency bands to prevent the interference between the particular systems.
- Frequency band should provide high speed transmission in a 5G network by a wide available continuous spectrum
- Frequency band should have well spreading properties.

In the current 4G, traditional wireless communication systems that employ "orthogonal resources" for multiple access are used. Orthogonal Frequency-Division Multiple Access (OFDMA) and Time Division Multiple Access (TDMA) are a pair of examples of Orthogonal Multiple Access (OMA) schemes [15]. This system is based on the use of different sources of multiple users independently of time or frequency. OFDMA method is widely utilized in 4G systems. The OMA technique does not adequately meet the 5G system requirements, but the Non-Orthogonal Multiple Access (NOMA) technique has all the necessary infrastructure for 5G communication technology as it contains features such as low latency, spectral efficiency, and high data rate. Thus, NOMA technique may meet 5G system requirements more appropriately [16]. It may not be possible to utilize orthogonal multiple access methods with increasing number of users [17], so NOMA may provide higher spectral efficiency. Unlike OMA, NOMA divides users into power or code domain, permitting multiple user to be served simultaneously in the same resource blocks. This NOMA principle is the basis of superposition coding (SC) at the transmitter side and the successive interference cancellation (SIC) at the receiver side [18].

NOMA methods are generally divided into 2 main categories. These are Power-Domain NOMA (PD-NOMA) and Code-Domain NOMA (CD-NOMA). Code-Domain NOMA includes many different methods in itself: Sparse-Code Multiple Access (SCMA), Low Density Spreading based CDMA (LDS-CDMA) and Low Density Spreading based Orhogonal Frequency-Division Multiplexing (LDS-OFDM). In LDS-CDMA, it helps to restrict the interference effect on each chip found in basic CDMA systems by utilizing low density propagation sequences. LDS-OFDM can be considered as a formation of LDS-CDMA and OFDM, where the information symbols are first propagated to low density propagation sequences and the resulting chips are transmitted to a number of sub-carriers [19]. There are many other techniques which are related to NOMA, one of them being Rate-Splitting Multiple Access (RSMA). In RSMA, the signals of different users in a group are superimposed and each user's signal spreads to the entire frequency/time source specified for the group [20].

1.1. Literature on NOMA

In the literature, studies on LDS method have been conducted for 5G communication technologies. As a generalisation of LDS-OFDM, [21] suggests to achieve a better block error rate (BLER) performance in the overloaded OFDM systems. In addition to many researches in the fields of PD-NOMA and LDS, there are also various studies on Sparse Code Multiple Access (SCMA) technique [22], which is the code based approach of NOMA. Complexity in the structure of the receiver, uncertainties in the codebook design, theoretical analysis of achievable rate and overloading have still been investigated in studies in the field of SCMA. One main area of studies has focused on codebook design. Compared with conventional Low Density Signature Multiple Access (LDSMA) systems with inherent repetition code (also called spreading), the multi-dimensional codebooks play a substantial role in the performance of SCMA systems [23]. The difference between SCMA and LDS-CDMA is that bit streams sent from different users are assigned directly to sparse codewords located at the transmitter. Thanks to the Message Passing Algorithm (MPA), the codewords sent to the receiver are decoded [24]. The most important advantage of the SCMA method over LDS is that it allows users to transmit multi-dimensional codewords (i.e. equivalent to transmitting data with multi-dimensional constellation points). In [25], Yu et al. offered a design method of SCMA codebooks based on star-quadrature amplitude modulation (star-QAM) signaling. In that study, OFDM systems also have to face different problems like high side lobes and large peak to average power ratio (PAPR) values, which lead to power inefficiency of multi-carrier

NOMA systems. The studies [26], [27], [28] have introduced the concepts, challenges, latest applications and future research trends of several promising NOMA techniques. In [29], the authors briefly have discussed the basic structure of the coordinated beamforming (CBF) NOMA technique and compared it to the conventional NOMA and OMA schemes. In [30], although FDMA/TDMA/CDMA application schemes effectively avoid the intra-beam interference and simplify the signal detection, a single orthogonal resource block can only serve one user and restricts further improvements on the spectrum efficiency (SE) and capacity for satellite networks. In [31] at the receiver side, propagation delay from the transmitter to the receiver is usually unknown. This delay must be estimated from the receiver signal in order to efficiently sample the output of the demodulator so it leads to time delay and complexity at the receiver. In [32], spectrum detection technique provides cognitive radio capabilities when implemented in the SCMA system in mmWave 5G technology. In [33], the SCMA method can significantly enhance the IoT performance compared to the conventional orthogonal frequency division multiple access system in terms of throughput, connectivity and task completion time on the condition that it is compatible with IoT processing capabilities to avoid undesired detection latency. In [34], based on the current channel acquisitions between users and the base station, three codebook assignment methods were proposed and SCMA was shown to have advantages compared to the conventional codebook assignment method. Furthermore, a method was proposed to maximize the minimum Euclidean distance by rotating the constellation points. In the current 5G research area, SCMA as one of the non-orthogonal multiple access methods, provides better link-level performance, energy efficiency and low complexity. In this thesis, it is aimed to address the issues in codebook design. For that reason, the conventional codebook structure of SCMA systems has been investigated and different approaches are proposed to design new codebooks so as to improve the performance of conventional codebooks [35].

1.2. Thesis Contribution and Summary

With the SCMA method, which is one of the most promising methods in the current NOMA research field, many new features such as higher data rate, more capacity and low latency would be the benefits. Although there are innovations brought by the SCMA method to our lives, there are some significant questions that need to be worked on in SCMA. Complexity of the receiver structure, performance improvement via the codebook design, theoretical analysis of achievable rates and overloading are still active research areas in the field of SCMA. In this thesis, the main focus is on SCMA codebook design, which is one of the most important issues in SCMA system design and directly affects the system performance. In each codebook, there are codewords, which are signal constellations with complex values that determine the gain of SCMA.

In this thesis, four new different approaches are proposed for codebook design considering the structure of the conventional codebook [36] in the literature. In the first approach, the distance between the points in the constellation sets is increased while keeping the signal constellation energy constant. In the second approach, the angles between the constellation sets in the first sub-carrier and all sub-carrier were set equal. In the third approach, which is also called the permutation method, [37] is adapted for the conventional codebook. New constellation sets were obtained by multiplying the points in the constellation sets on the first and second sub-carriers by the half-angle formula. In the last approach, in the codebook, five different users' constellation sets are transmitted over a total of four sub-carriers. With this new approach, it is proposed to increase the number of signal constellation sets. A new constellation set has been designed with its energy remaining constant. Four different approaches are studied in AWGN and Rayleigh fading channel structures for SCMA systems. The most important contribution of these proposed approaches is that approximately 1-2 dB gain has been achieved in terms of BER compared to the conventional codebook.

The rest of the thesis is organized as below. In Section 2, an overview of OMA and NOMA methods is presented. In Section 3, SCMA model is presented in detail including the general structure and transmitter model of SCMA, decoding with MPA and summarizing the codebook design literature. In Section 4, proposed or adapted codebook design approaches are presented in detail. In Section 5, simulation results are presented and explained in detail. The final section concludes the thesis and presents possible future research areas to explore.

2. MULTIPLE ACCESS TECHNOLOGIES

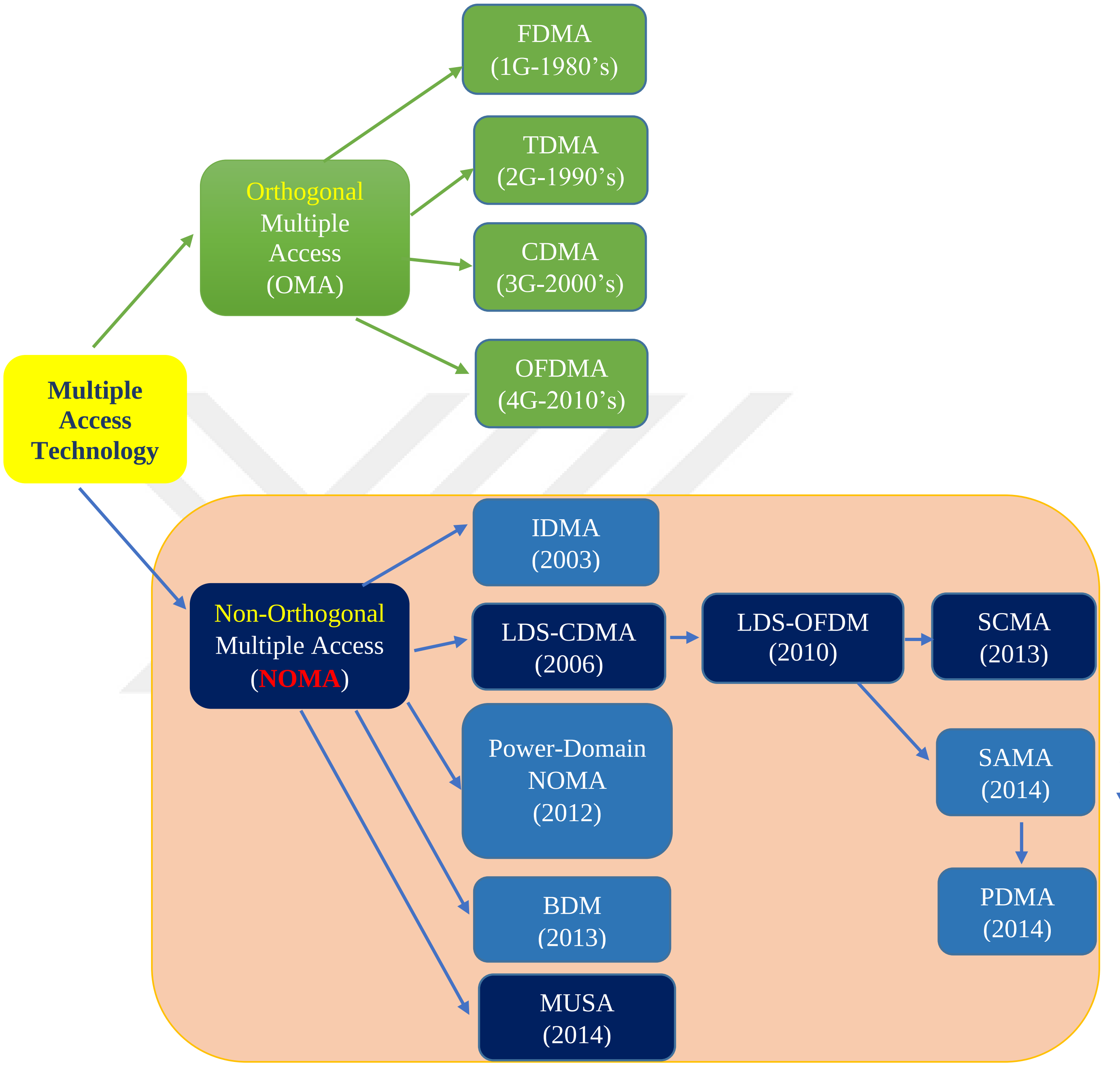

Fig. 1: The basic structure of multiple access technologies [38]

In this section, a general overview of multiple access technologies will be presented. In the last 20 years, with the rapid development of technology, wireless communication systems needed a radical change in order to have a transition from old to new generation communication systems with different multiple access capabilities. In particular, for the existing 1G, 2G, 3G and 4G wireless communication systems, Time Division Multiple Access (TDMA), Frequency Division Multiple Access (FDMA), Code Division Multiple Access (CDMA) and orthogonal frequency division multiple access (OFDMA) are used as different types of multiple access technologies [39], [40], whereas in future wireless systems NOMA methods may be possibly employed. As shown in Fig. 1, multiple access technology consists of two main parts, Orthogonal Multiple Access (OMA) and Non-Orthogonal Multiple Access (NOMA).

2.1. OMA

OMA technique is examined under three sub-titles, based on code, frequency and time due to the fact that resources are orthogonal for all users. In FDMA, radio frequency (RF) is divided into several small sub-channels. This method is used in analog and digital radios.

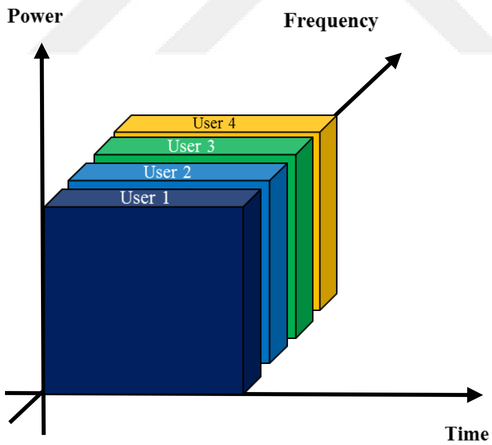

Fig. 2: Representation of FDMA [41]

According to TDMA method, RF channel is divided equally according to time instead of the frequency. Each slot is suitable for separate conservation structure.

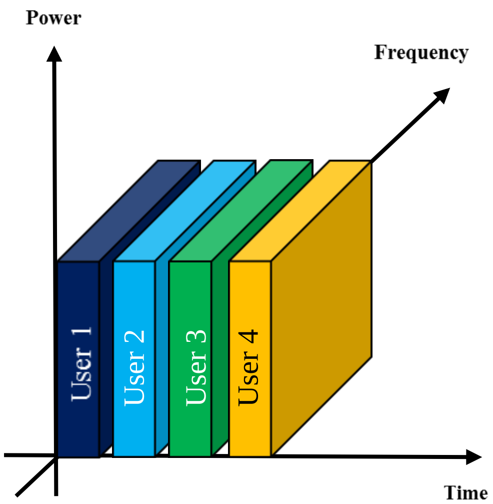

Fig. 3: Representation of TDMA [41]

In Code Domain Muliple Access (CDMA), multiple users can share out the information in the same time-frequency block. Unlike FDMA, transmitted signal uses the same frequency slot. Unlike TDMA, signals are transmitted simultaneously.

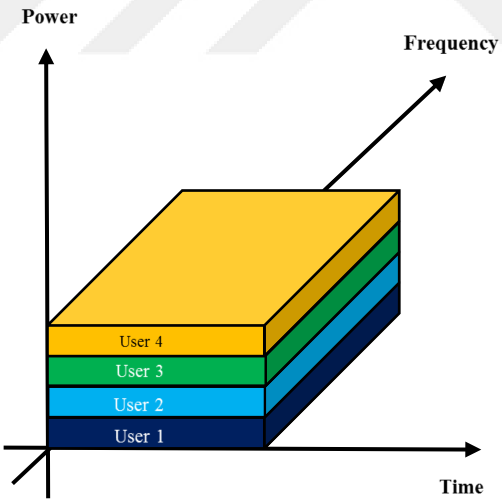

Fig. 4: Representation of CDMA [41]

The OFDMA method is the method that allows multiple users to divide the existing bandwidth into many channels and assigns different users to these channels [41]. The most important advantage of this method compared to FDMA method is that the channels are placed more frequently to each other and the spectrum is used more efficiently.

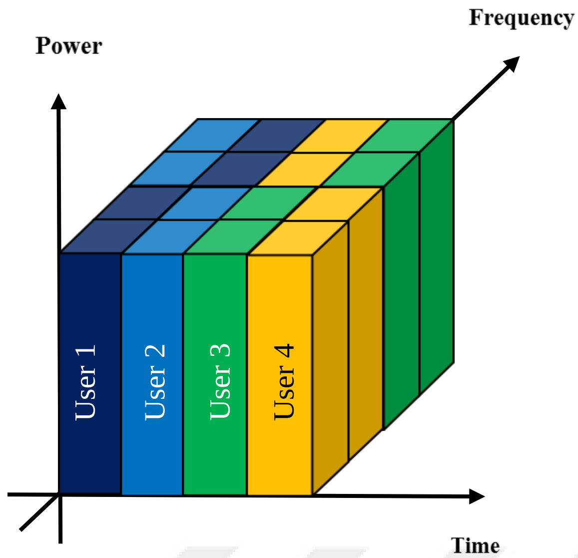

Fig. 5: Representation of OFDMA [41]

2.2. NOMA

In the current 4G-LTE cellular networks OMA techniques are employed. 5G communication systems do not meet the system requirements because infrastructure of 4G-LTE is not appropriate for the 5G technology. However, the new concept of NOMA technique has been proposed to promote multiple users over orthogonal time, frequency and code domain resources.

NOMA techniques are basically split into two main parts. These are Power Domain NOMA (PD-NOMA) and Code Domain NOMA (CD-NOMA). The working principle of PD-NOMA is illustrated as in Fig. 6.

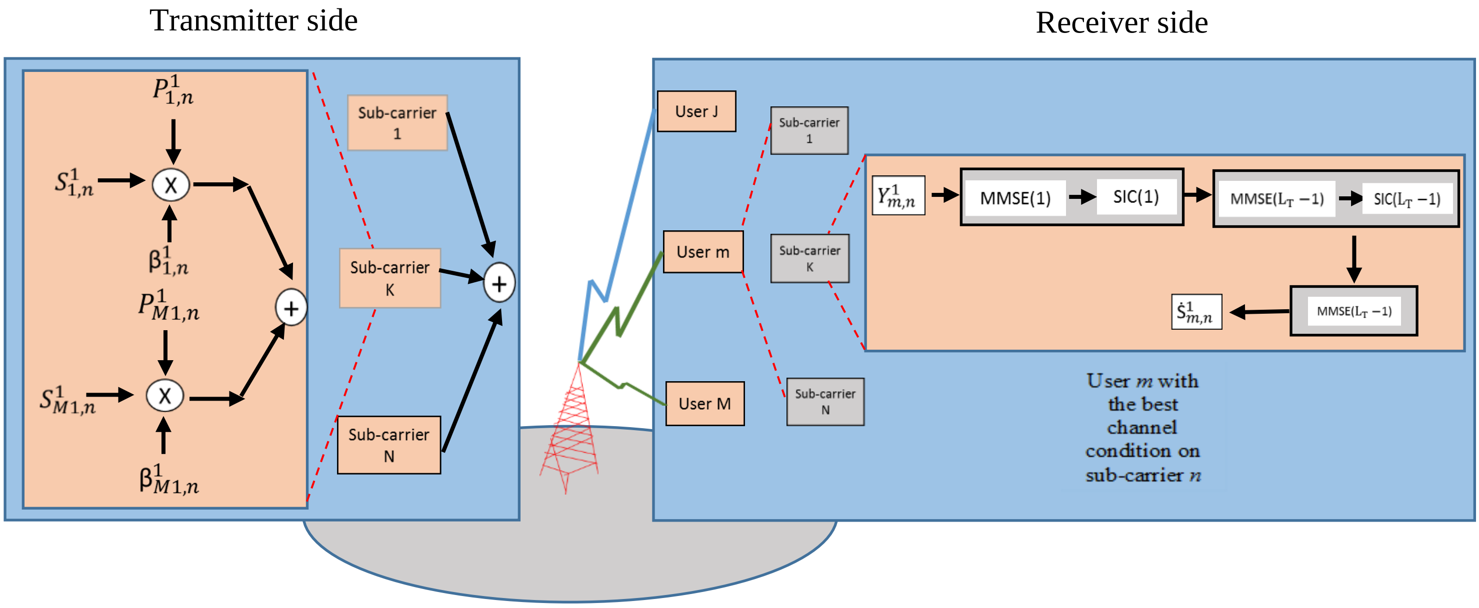

Fig. 6: Representation of the transmitter and receiver structure in the PD-NOMA system [42]

In PD-NOMA, each sub-carrier can be assigned to more than one user at the same time, thanks to the superimposed coding (SC), and users benefiting from the successive interference cancellation (SIC) eliminatimg the signals of other users. Based on the PD-NOMA approach, each user in the receiver eliminates the signals of users with worse channels and accepts the signals of users which are remaining as noise [42].

The code domain NOMA method has originated from classic CDMA systems, where multiple users share time and frequency resources simultaneously but adopt unique propagation sequences unique to each user [38]. Code Domain NOMA methods are divided into many schemes. These are namely LDS [43], SCMA [21], Multi User Shared Access (MUSA) [44] and Successive Interference Cancellation Amenable Multiple Access (SAMA) [45]. LDS approach is one of the methods obtained from Code Domain Multiple Access system. The concept of LDS-CDMA which implies that each transmitted symbol is over only a few restricted number of chips; i.e., a few non-zero elements on the sparse spreading sequences, is as shown in Fig. 7.

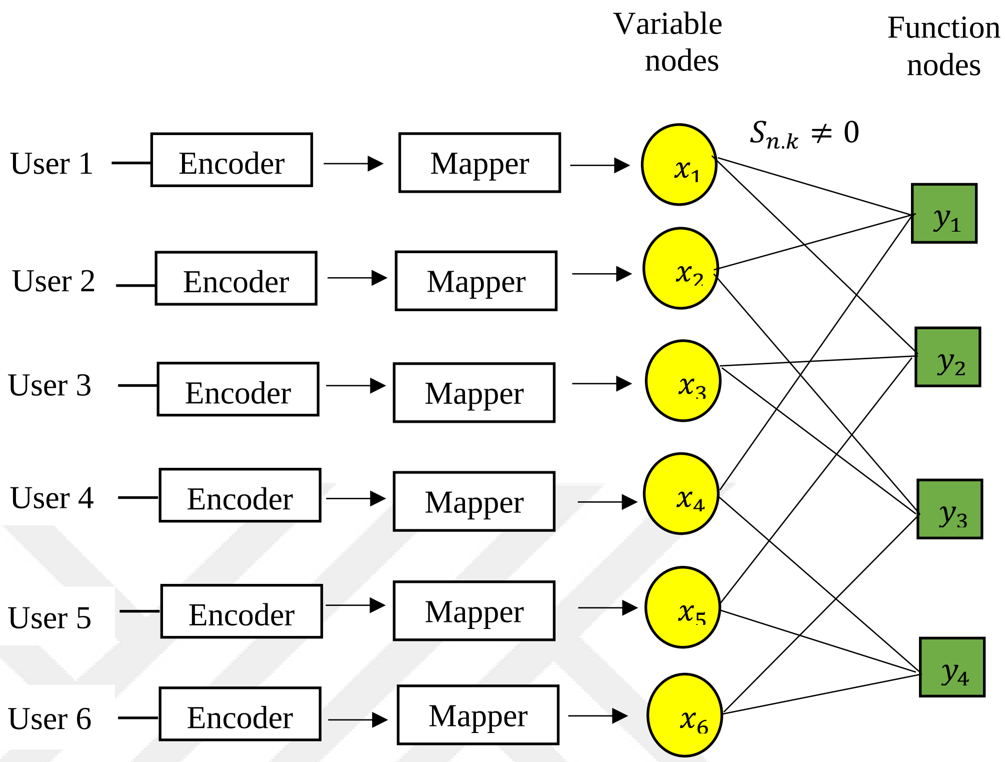

Fig. 7: Explanation of LDS-CDMA: 6 users getting 150% overloading rate using only 4 chips for transmission [38]

The LDS method, which can promote massive connectivity with non-orthogonal low density signatures, is considered as a multiple access method to be utilized in future 5G systems [46].

The SCMA technique [21] is one of the NOMA methods derived from the basic LDS-CDMA schemes based on code field multiplexing. SCMA has similar features with the LDS-CDMA method from the point of factor graphic representation and analyzing the message passing algorithm at the receiver. Main difference from the basic LDS-CDMA is as shown in Fig. 8. The spreading operation and bit to constellation mapping are fundamentally combined in SCMA, so, the original bit information is directly mapped to sparse codeword which consists of a few non-zero items, where each user has a codebook containing its own information.

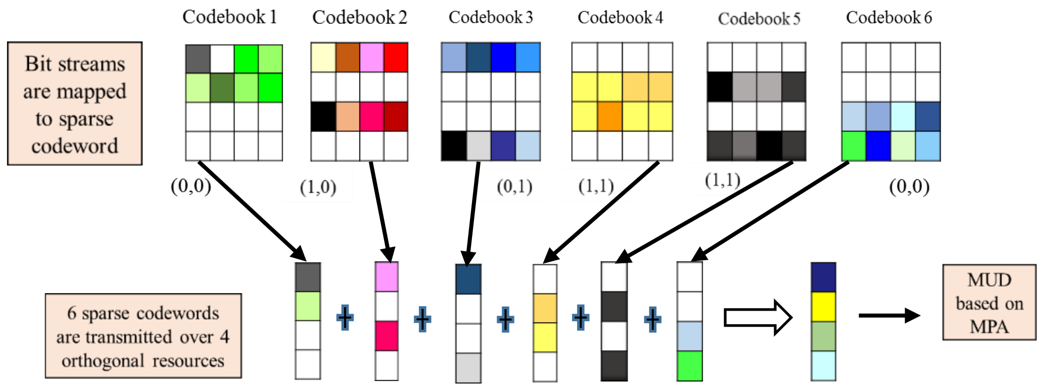

Fig. 8: SCMA encoding and multiplexing [38]

MUSA is an alternative NOMA scheme which is based on code domain multiplexing for an improved CDMA scheme. In MUSA, the user's information is spread utilizing a special spread sequence, and due to this spread, overlap occurs and is transmitted from the channel to the receiver. At the receiver side, it is aimed to successfully demodulate the overlapping data of each user by using the SIC receiver [47]. The basic concept of MUSA method is shown below in Fig. 9.

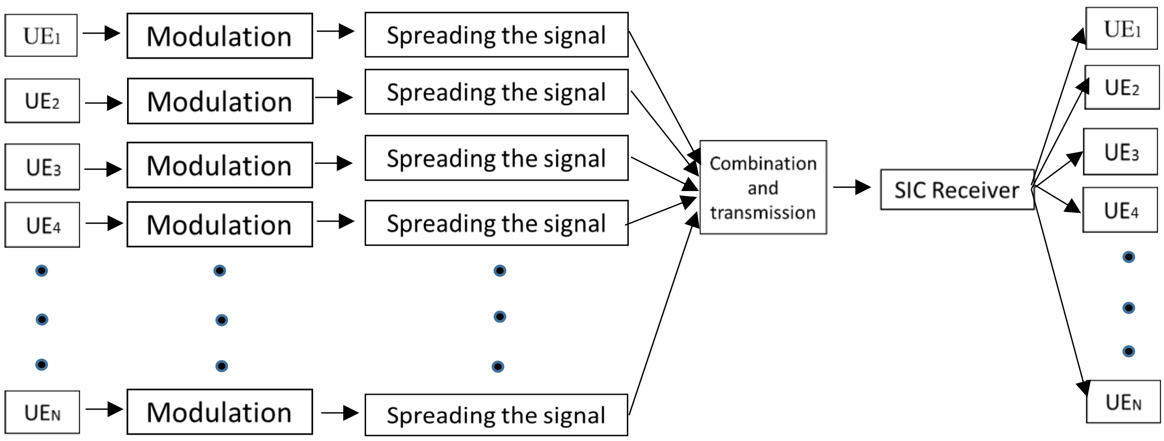

Fig. 9: Basic concept of Multi User Shared Access (MUSA) [47]

3.SPARSE CODE MULTIPLE ACCESS

In this section, firstly general structure of the SCMA will be presented followed by the general model and the transmitter structure. Then, SCMA decoding with MPA will be discussed. The section will be concluded with SCMA Codebook Design Literature.

3.1. General Model and Transmitter Structure

There are many studies about SCMA systems in the literature. Detailed studies are carried out considering many different aspects from the system requirements to system performance. The SCMA system was first proposed in the literature [21] as a new multiple access technique in NOMA by authors named H. Nikopour and H. Baligh under the name "sparse code multiple access". Basically, the scheme of the proposed SCMA method is shown in Fig. 10.

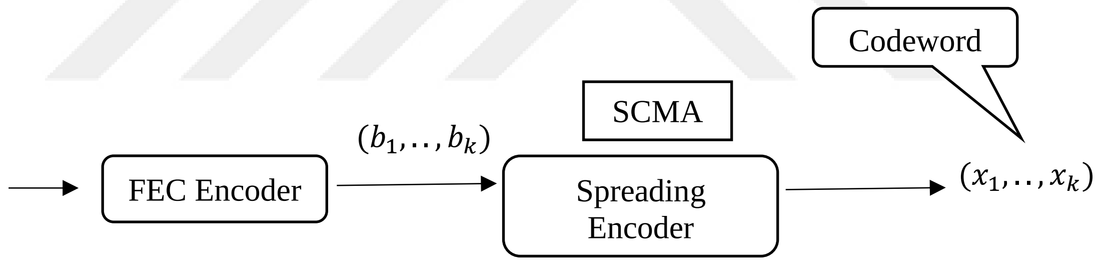

Fig. 10: Basic concept of SCMA system [21]

According to this scheme, the encoded bits in the SCMA system are first transmitted to the FEC Encoder. The purpose of the FEC Encoder is to check whether there are any fault conditions in the coded bits. Coded bits called b_k are sent to Spreading Encoder after FEC Encoder. Here, these bits are assigned directly to sparse codewords. The codewords, called x_{kj} form codebook for each user.

Codebook design is one of the most important aspects that affect the SCMA performance. Using the codewords in the codebook, the information bits contained for different users are encoded into these codewords and sent to the receiver. There is a factor graph matrix that shows which users are sending their information bits over which sub-carriers. The factor graph matrix is a matrix with **F**, (K rows and J columns), and in other words, determines the sub-carrier relationship with users. In the literature, the most frequently used matrix is given in (1) for $J = 6$ and $K = 4$.

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

In the SCMA system, in this model, where each codebook consists of M codewords in length K, J represents the number of users. K also shows the number of sub-carriers. $J > K$ condition indicates an overloading condition. Overloading factor is shown as λ. For non-orthogonal condition $\lambda > 1$, the number of resources is less than the number of users so, multiple layers collide over the resource. This also means that J codewords are sent via the K sub-carriers. An uplink SCMA system model wih $J = 6$ and $K = 4$ is shown below as in Fig. 11.

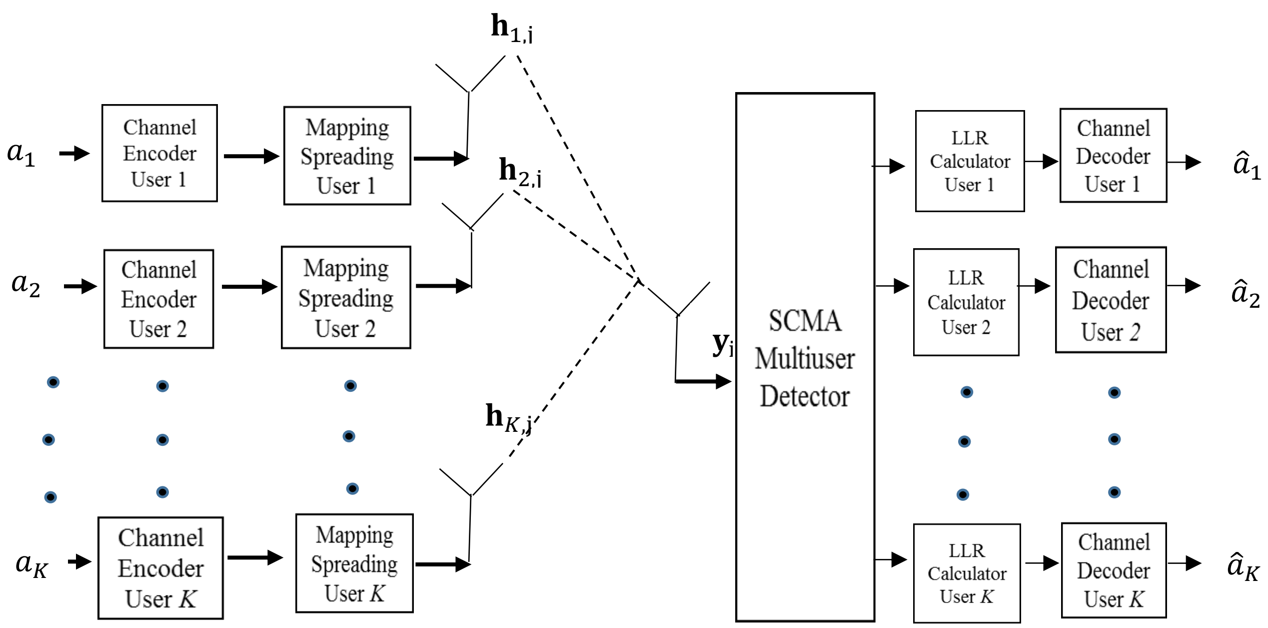

Fig. 11: SCMA Uplink System Model [48]

An SCMA encoder can be expressed as [49]

$$f : \mathbb{B} \log_2 M \rightarrow \chi , \quad \mathrm{x} = f(b) \tag{2}$$

where χ is a complex number set with set number $|\chi| = M$ and $\chi \subset \mathbb{C}^K$, and M denotes the number of constellation points for each user on a sub-carrier. " $\log_2(M)$ " value of set $\mathbb{B}$ specified in function f shows that there are binary combinations for each set element.

The vector **b** indicates the set of binary numbers, **x** is a sparse vector with a K-dimensional complex codeword from χ and the number of non-zero elements in each codeword is denoted by N. Fig. 12 indicates a typical SCMA encoder with $N = 2$, $K = M = 4$.

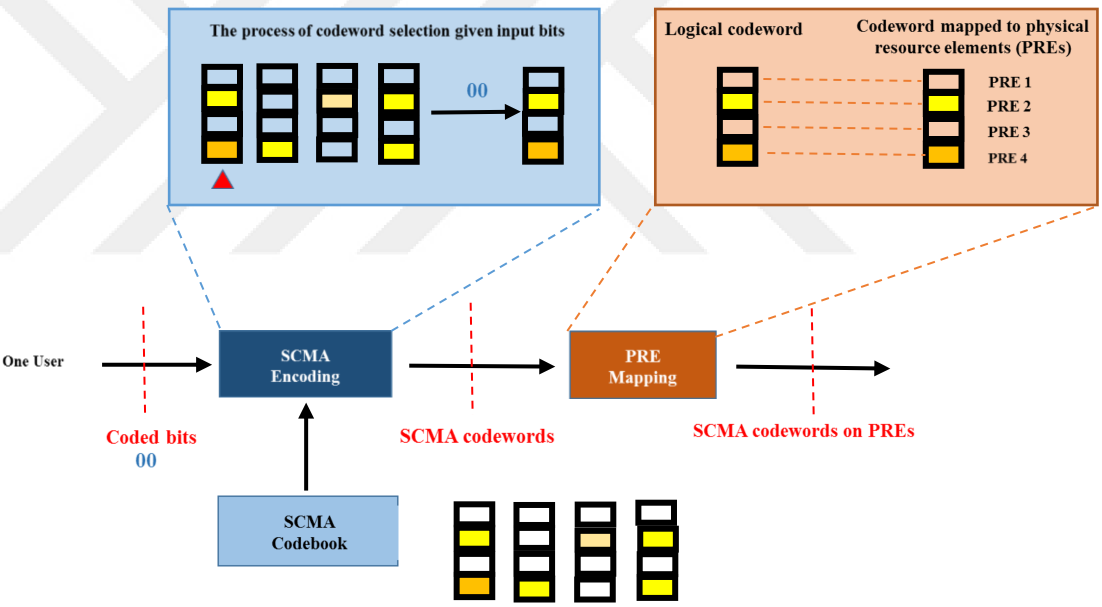

Fig. 12: SCMA Encoder Structure [36]

The encoded data bits of user j are assigned to a multidimensional codeword $\boldsymbol{c}_j$ in the codebook selected for user j. The SCMA codebook involves M codewords, each codeword involves K physical resources with N non-physical elements.

The signal of the user reaching the k-th sub-carrier at the receiver side can be shown as follows:

$$y_k = \sum_{j=1}^{J} \boldsymbol{h}_{kj} \boldsymbol{x}_{kj} + \boldsymbol{n}_k \tag{3}$$

Here, $\boldsymbol{x}_{kj}$ is the codeword of $\mathbf{x}_j$ indicating the element k for the j-th user, $\mathbf{h}_{kj}$ is the channel coefficient gain of the j-th user in the k-th sub-carrier and $\boldsymbol{n}_k$ is the complex-valued noise term. The signal in the receiver can be expressed as a vector representation for all sub-carriers as follows:

$$\mathbf{y} = \sum_{j=1}^{J} \mathrm{diag}\left(\mathbf{h}_j\right) \mathbf{x}_j + \mathbf{n} \tag{4}$$

$\mathbf{x}_j = \left[x_{1j}, x_{2j}, \cdots, x_{Kj}\right]^T$ is the SCMA codeword of the j-th user, $\mathbf{h}_j = \left[h_{1j}, h_{2j}, \cdots, h_{Kj}\right]^{\boldsymbol{T}}$ is the channel gain for the j-th user, and $\mathbf{n}$ indicates the Gaussian noise.

At the receiver, there are fewer user signals in each sub-carrier than the total number of users, therefore, multiple user detection techniques based on a reasonably complex Message Passing Algorithm (MPA) can be implemented.

3.2. SCMA Decoding with MPA

At the receiver, data from different users are coded into the SCMA codebook via sub-carriers after passing through the channel. The detection of the transmitted data is quite complex. MPA technique should be applied to solve this complexity at the receiver. In other words, it is aimed to successfully detect the information sent from the transmitter with low complexity. MPA [50], is a repetitive and optimal detection algorithm on the basis of bidirectional factor graph that models the receiver structure as shown below in Fig. 13.

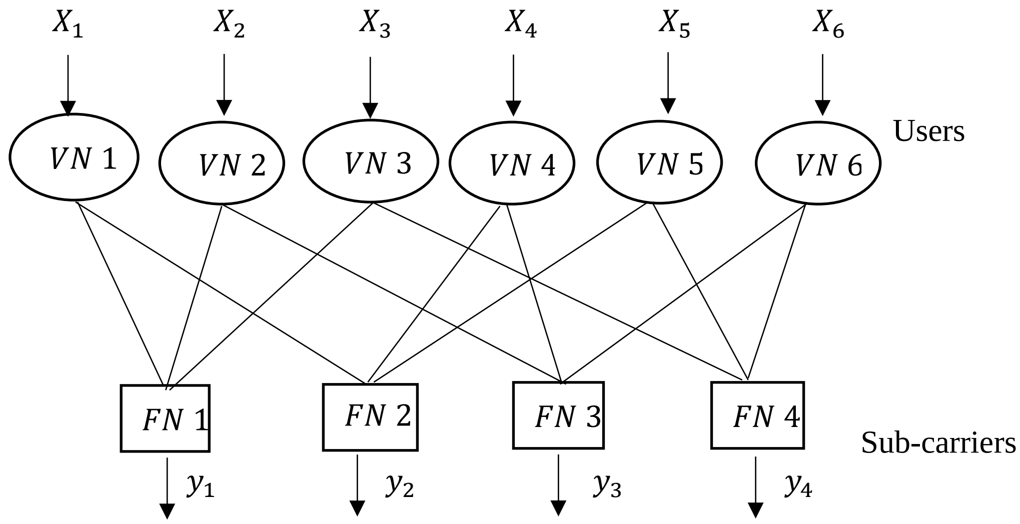

Fig. 13: Representation of MPA factor graph with 6 users and 4 sub-carriers [50]

MPA factor graph has two different types of nodes which are named as function nodes (FNs) and variable nodes (VNs). FNs symbolize the number of K sub-carriers. VNs symbolize the number of J users. The working principle of MPA is an iterative process. Message information is constantly updated due to variations between function nodes and variable nodes. After obtaining the probability estimate of codeword at each layer, the Log-Likelihood-Ratio (LLR) for each coded bit is calculated. There are three steps for the MPA decoder. **The first step** is the initial calculation of the conditional probability. For each FN, f_n function is calculated firstly as shown in (5), that is the set of all possible residual signals. $h_{n,k}$ represents the known channel and $C_{k,n}(m_k)$ represents the codeword.

$$\mathrm{f_n}\left(y_n, m_1, m_2, m_3, \mathrm{N_{0,n}}, \mathrm{H_n}\right) = \frac{-1}{\mathrm{N_{0,n}}} \left\| y_n - (h_{n,1} C_{1,n}(m_1) + h_{n.2} C_{2,n}(m_2) + h_{n,3} C_{3,n}(m_3)) \right\|^2 \tag{5}$$

$$\mathbf{\Phi}_{\mathrm{n}} = \exp(f_n\left(y_n, m_1, m_2, m_3, N_{0,n}, H_n\right)) \tag{6}$$

$\mathbf{\Phi}_{\mathrm{n}}$ function is the conditional probability for given codeword combination. Exponential operation (6) is applied to f_n function for Gaussian noise condition since the storage area will be the same. A prior probability is assigned to each codeword for preparing the iterations where the probabilities are assumed to be equal as

$$I_{v1\to g}^{init}(m_1) = I_{v2\to g}^{init}(m_2) = I_{v3\to g}^{init}(m_3) = \frac{1}{M}\,. \tag{7}$$

The **second step** of SCMA decoding process is the iterative message passing along edges. This step consist of two parts which are namely as an FN update and a VN update. These updates are shown with equations (8) and (9). The messages pass from the function nodes to their connected variable nodes and from variable nodes to their connected function nodes, iteratively [36].

$$I_{g\to v_1}(m_1) = \Sigma_{m2=1}^{M} \sum_{m2=1}^{M} \mathbf{\Phi}_{\mathrm{n}}((\, I_{v_2\to g}\,(m_2)\, I_{v_3\to g}\,(m_3)) \tag{8}$$

$$I_{v\to g_1}(m) = normalize\ (ap_v(m) I_{g_2\to v}(m)) \tag{9}$$

The algorithm needs to iterate adequately. After N iterations, it is a collection of information from all other neighboring FN nodes and a prior probability at v in the VN nodes for M codebooks and

$$Q_v(m) = ap_v(m)\, I_{g_1\to v}(m) I_{g_2\to v}(m)\,. \tag{10}$$

After obtaining the probability estimate of the codeword at each layer, for each coded bit, the Log-Likelihood-Rate (LLR) in equation (11) is calculated.

$$LLR_X = \log\ \frac{P(b_x=0)}{P(b_x=1)}$$

$$LLR_x = \log\frac{\Sigma_{\mathrm{m:b_{m,x}=0}}\ Q_{\mathrm{v}}(\mathrm{m})}{\Sigma_{\mathrm{m:b_{m,x}=1}}\ Q_{\mathrm{v}}(\mathrm{m})} = \log(\, \sum_{\mathrm{m:b_{m,x}=0}} Q_v(\mathrm{m})) - \log(\, \sum_{\mathrm{m:b_{m,x}=1}} Q_v(\mathrm{m})) \tag{11}$$

3.3. SCMA Codebook Design Literature

There are several methods on SCMA codebook design in the literature. In [51], the constellation point design was conducted to maximize the speed limit of a multi-input-multi-output system. In [52], codebook design was made by changing the energy diversity parametrically in Quadrature Amplitude Modulation (QAM) constellation points. In [53], the performance results of two different codebooks obtained with the phase-amplitude approach are presented. The common feature of these studies is to show how much performance gain will be obtained by changing the parameters of the proposed method. Another study offers a new design method for the multidimensional mother constellation in the SCMA codebook using circular QAM, which can work efficiently and at the same time decrease the complexity of MPA [54]. The main principle in the design of lattice constellations is that the main constellations that constitute this lattice type have a good Euclidean distance. By applying different constellation operators such as phase transformations to these constellations, codebooks of different sizes are formed for different constellations [55]. In [56], the authors designed various codebooks of different sizes for different performance needs, such as connections, capacity and coverage requested by different users, and designed SCMA mapping on the basis of an irregular SCMA structure that can make short delays and large connections simultaneously in the same system. Factors related to the design rules of lattice constellations for a new SCMA codebook design method have been proposed in [23], and SCMA has indicated to perform better than LDS because of the shaping gain from multi-dimensional codebooks. In another study, there are two important aspects for the codebook design. The first step is to design the mother constellation. In the second step, user-specific operations such as complex conjugation and phase rotation should be applied on the mother constellation, which is designed to create the final codebooks [57]. In [58], a new method is proposed for the SCMA codebook design for downlink SCMA systems using gold angle modulation. Golden Amplitude Modulation (GAM) method is a method that can offer PAPR performance and improved mutual information (MI) on square QAM design. In studies [59], [25], [60], [61], [62], even though many of the present codebook design methods for downlink systems ensure good-performing codebooks, they suffer a significant loss in performance in uplink systems. In the literature, there are limited number of studies for uplink SCMA systems related to the design of SCMA codebooks. In [63], the authors suggest joint design of multi-user codebooks through uplink Rayleigh fading channels for uplink SCMA systems. Nevertheless, it is limited to small size and/or low dimension codebook for designing SCMA codebooks.

4.SCMA CODEBOOK DESIGN

In this chapter, after initially explaining the conventional codebook, we will present four different design approaches under the methods proposed in Chapter 4.2.

4.1. Conventional Codebook

The design of the constellation points in the codebook plays an important role in the performance of an SCMA system. In the literature, the codebook designed in accordance with the factor graph matrix given in (1) for $J = 6$ and $K = 4$ is given in [54]. Accordingly, each user sends 2-bit information by selecting one of $M = 4$ constellation points on $d_v = 2$ different sub-carriers. Therefore, $d_f = 3$, i.e. three different users' signals are transmitted on each sub-carrier. Considering the conventional codebook design, the constellation points transmitted on the first sub-carrier are shown in Fig. 14.

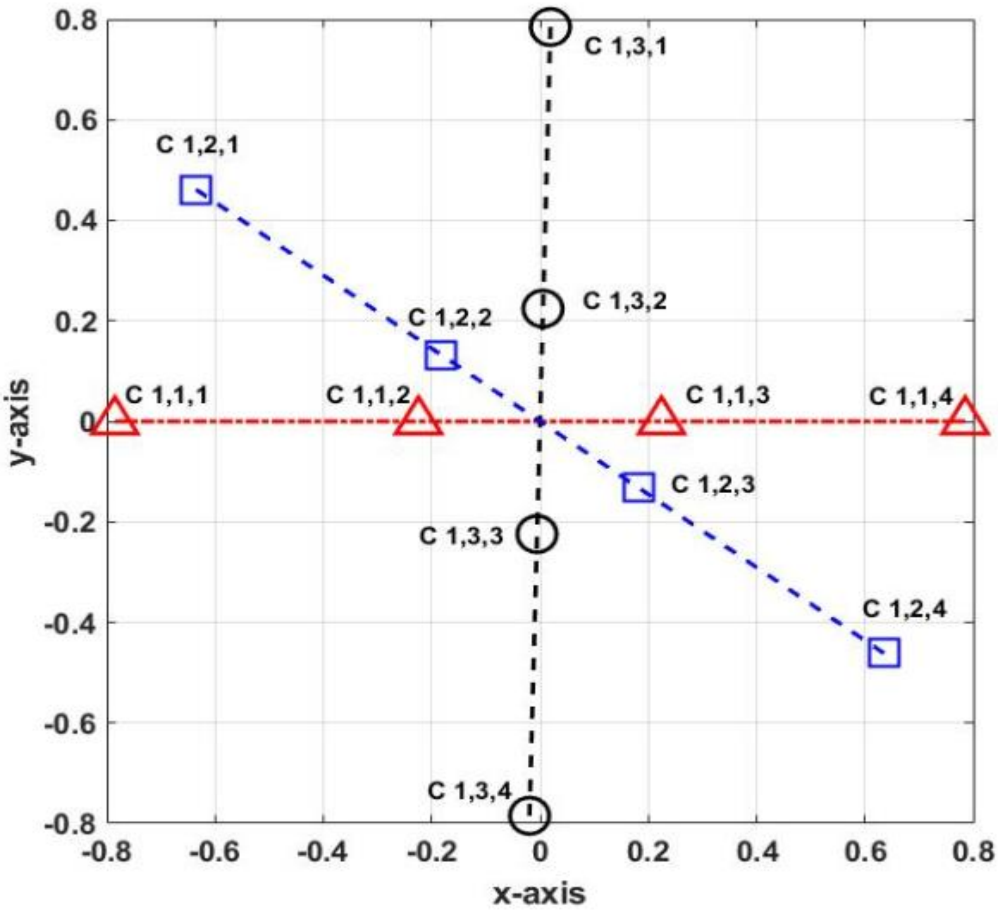

Fig. 14: Constellation points on the first sub-carrier of codebook

To further describe the SCMA codeword representation given in (11), let us redefine the point set with complex values as $c_{k,j,m}$. Here $k \in \{1, 2, \dots, K\}$ denotes the sub-carrier index, $j \in \{1, 2, \dots, d_f\}$ indicates the user index, and $m \in \{1, 2, \dots, M\}$ indicates the message information. In Fig. 14, where $k = 1$, the constellation points are presented for $d_f = 3$ and $M = 4$.

4.2. Proposed Approaches

In this thesis, it is aimed to achieve a better system performance compared to the conventional codebook usage by maximizing the distance between the points in the constellation sets in the conventional, i.e., commonly used codebook. Four different approaches have been proposed or adapted in this study.

<u>1st Design Method:</u> In the first approach, the main purpose is to increase the constellation set points on the first sub-carrier and a better performance is expected compared to the conventional codebook. Maximizing the minimum Euclidean distance between points in the studies conducted in the literature [49], this approach supports our study. Firstly the Euclidean distances between the constellation sets in the conventional codebook are calculated, the distance between the closest points of the constellation sets is gradually increased and new constellation sets are created from these points, provided that their energy remains constant. This approach is presented in Algorithm 1. Here $\varepsilon_{k,j}$, represents the energy of j-th user's constellation sets on the k-th sub-carrier, $\|\,.\,\|$ operator stands for the Euclidean norm, $d_{k,j,m}$ are the distance values of other constellation points relative to the m-th constellation points, $(d_{k,j,m})_{\min}$ is the smallest Euclidean distance. Our approach is different from [49] in a way that increasing the smallest distance by Δ, new constellation points are defined, and provided that the energy remains constant, the points with the greatest Euclidean distance are brought close to each other.

Algorithm 1: Approach to increase the distance between the constellation points

for $\mathbf{c}_{k,j} = [c_{k,j,1}, c_{k,j,2}, \cdots, c_{k,j,M}]$ **do**
  Calculate $\varepsilon_{k,j} = \|\boldsymbol{c}_{k,j}\|^{\mathbf{2}}$
for $k = 1{:}K$; $j = 1{:}d_f$; $m = 1{:}M$
  $d_{k,j,m} = \|c_{k,j,m} - c_{k,j,m'}\|$; $m \neq m'$
end
for $(d_{k,j,m})_{\min}$; $j = 1{:}d_f$
  $(d_{k,j,m})_{\min} \leftarrow (d_{k,j,m})_{\min} + \Delta$
  $c_{k,j,m} \leftarrow (c_{k,j,m})_{new}$
  Check $\varepsilon_{k,j} = (\varepsilon_{k,j})_{new}$

```
    end
end
```

<u>2nd Design Method:</u> In this approach, there are three different constellation sets in each sub-carrier in the codebook. It is suggested that the angles between each constellation set in the sub-carrier should be equal to 60°. The reason for choosing the equal angle adjustment is that, as it is known, four points in each set of constellation are linearly symmetrical in the coordinate plane and located in two different regions.

Therefore, since the constellation points on different sub-carriers are positioned at different angles among themselves, the angles between user constellation points are adjusted to be equal to π/d_f and the constellation points are generated. In the case where the narrow angle between two constellation point is indicated by $\theta_{k,j}$, the approach to obtain new constellation points is given in Algorithm 2. Here, the x and y variables indicate the coordinates of each point in the j-th constellation set, which is linear, and each constellation point is rotated clockwise with the angle $(\pi/d_f - \theta_{k,j})$. The energies of newly formed constellation sets do not change.

Algorithm 2: Obtaining constellation set with phase-amplitude rotation

for $\mathbf{c}_{k,j} = [c_{k,j,1}, c_{k,j,2}, \cdots, c_{k,j,M}]$ **do**

  Calculate angles $\theta_{k,j}$; $j = 1{:}\,d_f$

 for $j = 1{:}\,d_f$

  $(\boldsymbol{c}_{k,j})_{new} = (x\cos(\pi/d_f - \theta_{k,j}) - y\sin(\pi/d_f - \theta_{k,j}),\ x\sin(\pi/d_f - \theta_{k,j}) + y\cos(\pi/d_f - \theta_{k,j}))$

   $c_{k,j,m} \leftarrow (c_{k,j,m})_{new}$

end

end

3rd Design Approach:. With this method, called the permutation method, it is aimed to reduce complexity in the codebook by using the e^{i90} half-angle formula of the complex numbered constellation set points on the sub-carriers. This method is given in [37] and is adapted to the conventional codebook that we have considered, and the system performance is explored. In the conventional codebook, the information bits of six different users are sent over four different sub-carriers. When these transmitted bits are examined, it is observed that the information transmitted over the first sub-carrier and the fourth sub-carrier are the same. The same condition is valid for the information sent over the second sub-carrier and the third sub-carrier. The difference between the sub-carrier pairs is that the same information belonging to different users is sent over these sub-carriers to provide diversity. For example, the information of the first, second and third users is carried over the first sub-carrier, and the third, fifth and the sixth user information is transmit over the fourth sub-carrier. By transmitting information belonging to different users through different sub-carriers, constellation sets in the codebook are generated. Therefore, by applying this half angle formula on first and second sub-carriers, a new constellation set points were created for the third and fourth sub-carriers. A new constellation set points for the third and fourth sub-carriers are shown below as follows.

$$K_3 = K_2 e^{i\theta}$$

$$K_4 = K_1 e^{i\theta}$$

When points consisting of complex numbers in the $(x + iy)$ format are sent via the codebook, it causes complexity in the detection of the signal at the receiver side with noise. This condition affects negatively the performance of codebook. Here, the permutation approach algorithm obtained by multiplying the complex numbered points found in different sub-carriers by $\cos 90 + i \sin 90 = (\cos 90 + i \sin 90)^1 = e^{i90}$ half-angle formula is presented in Algorithm 3.

Algorithm 3: Obtaining constellation set with the permutation method

1: **for** $\mathbf{c}_{k,j} = [c_{k,j,1}, c_{k,j,2}, \cdots, c_{k,j,M}]$ **do**
2: $k = 3{:}K$ and $k_1 = 1{:}K-2$
3: check $c_{k,j,m} = c_{k_1,j,m}$
4: **for** $(\boldsymbol{c}_{k,j})_{new}$
5: $(\boldsymbol{c}_{k,j})_{new} = (\mathrm{c}_{k1,j}).(\cos\frac{\pi}{2} + i\sin\frac{\pi}{2})$
6: $c_{k,j} \leftarrow (c_{k,j})_{new}$
7: check $\varepsilon_{k,j} = (\varepsilon_{k,j})_{new}$
8: **end**
9: **end**

<u>4th Design Method:</u> A total of five different information data is sent over four sub-carriers in the conventional codebook. The purpose of this approach is to increase the number of information data in the constellation sets belonging to the users and to provide diversity. The energy of the new designed constellation set is created to be equal to the energy of the other constellation sets. When each sub-carrier in the codebook is examined, it is seen that data set [0.7851, -0.2243, 0.2243, -0.7851] is used by different users in all four sub-carriers. In the proposed method, it was calculated by considering the principle of increasing the minimum Euclidean distance between the other constellation sets while essentially creating the points in the new constellation set. In Fig. 15, the new constellation set is shown by calculating these distances.

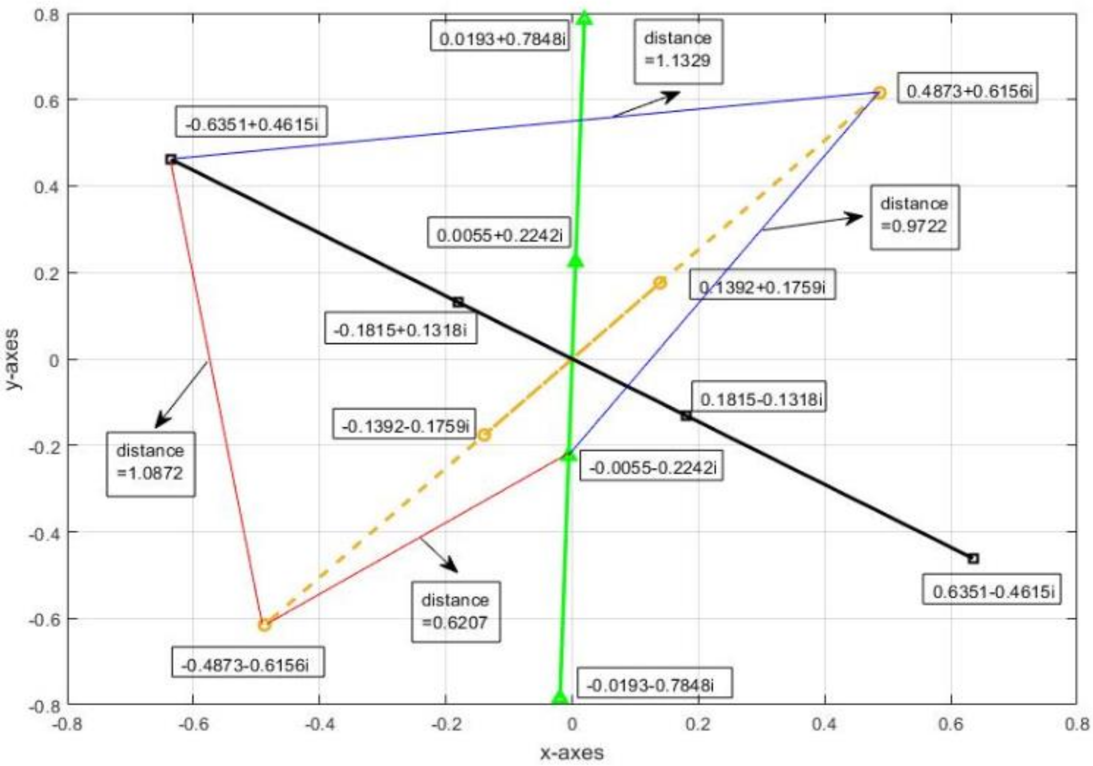

Fig. 15: Distance between constellation points on first sub-carrier

[0.4873 + 0.6156i, -0.1392-0.1759i, 0.1392 + 0.1759i, -0.4873-0.6156i] information is sent over the yellow sub-carrier in Fig. 15. In the new proposed method, how the points in this constellation set are obtained is determined by the distance between points in other constellation sets. New constellation design method is presented in Algorithm 4.

Algorithm 4: New constellation design method

for $\mathbf{c}_{k,j} = [c_{k,j,1}, c_{k,j,2}, \cdots, c_{k,j,M}]$ **do**
check $\varepsilon_{k,j,m} = \varepsilon_{k,j,m'}$
then
find new consellIation points
for $k = 3{:}\mathrm{K}$ and $m = 1{:}M$
$d_{k,j,m} = \|c_{k,j,m} - c_{k,j,m'}\|; \quad m \neq m'$
$c_{k,j,m} \leftarrow (c_{k,j,m})_{new}$
check $\varepsilon_{k,j} = (\varepsilon_{k,j})_{new}$
end
end

5. SIMULATION RESULTS

In this section, we will initially present the simulation setup followed by the computation time and performances of the proposed approaches that increase the distance between the constellation points, use phase-amplitude rotation, perform permutation method and consider the new constellation design method.

5.1.Simulation Setup

In this section, bit-error-rate (BER) of SCMA systems at different signal-noise-ratio (SNR) values have been obtained by using the conventional codebook and the codebooks obtained from four algorithms proposed in this thesis. System parameters are determined as $J = 6$, $K = M = 4$, $d_f = 3$ and $d_V = 2$. When the transmitted signals pass through the Additive White Gaussian Noise (AWGN) or Rayleigh fading channels, the user data are detected with the MPA approach.

5.2. Computation Time

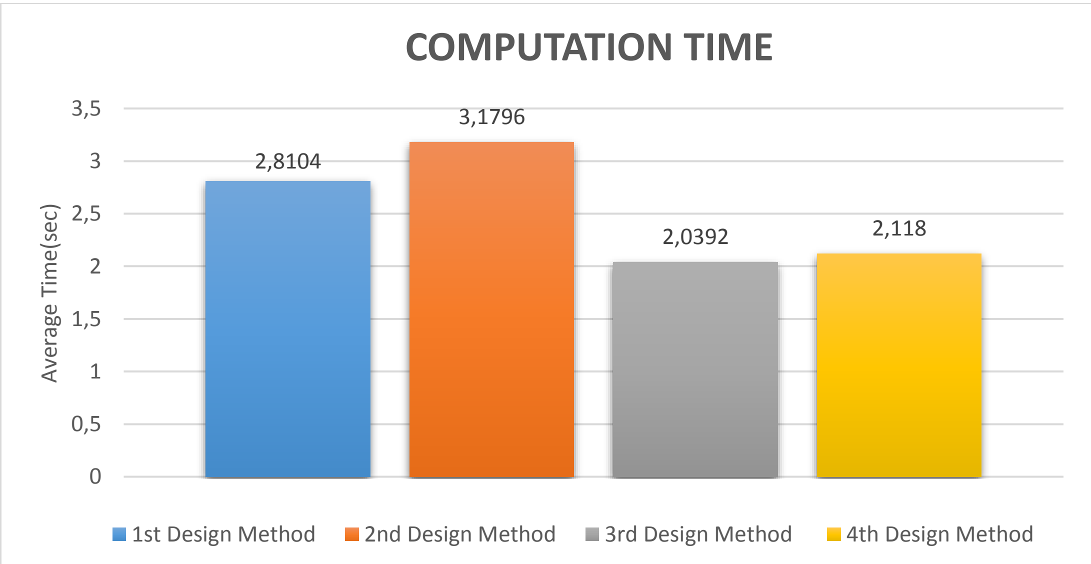

Fig. 16: Computation time of 4 different design methods

Initially, the complexity of the 4 different design methods that we have proposed has been examined in terms of computation time. While calculating the computation time of the algorithms, only the computation time of signal constellations has been calculated independent of BER and SNR values. Computation time graph of 4 different methods can be seen in Fig. 16. Based on the results obtained, the second method is the method with the highest computation time with more than 3 seconds. The reason for this is that it adjusts the angles between the half-angle formulas used in the algorithm and constellation sets to be equal to 60°. Since the half angle formulas are used, it directly affects the computation time. In the first method, the complexity increases when the angle is gradually increased between the constellation points in the algorithm and the noise factor is added. The computation time of the fourth method is slightly more than the third method. Since the number of the data sets to be transmitted is increased in total, the computation time has become higher compared to third method. In the third method, the new constellation set for the third and fourth sub-carriers was obtained by multiplying the existing constellation points on the first and second sub-carriers by a half angle of $\cos 90^{\circ} + i \sin 90^{\circ} = e^{i90^{\circ}}$. The computation time of the third method has the least value compared to the other 3 methods. Consequently, according to the computation time graph in Fig. 16, the order of computation time from high to low is Method-2, Method-1, Method-4 and Method-3.

5.3. Performance Results

Next, performance results are examined. In Fig. 17, comparative BER performances are presented when the distance between the constellation sets points obtained by Algorithm 1 is changed, when the constellation sets' energies remain constant. It can be observed that better and worse BER performances are obtained, respectively, by increasing and decreasing the distance of the constellation sets only in the first sub-carrier compared to the conventional codebook. As the smallest Euclidean distance values of the constellation sets were increased, approximately 1dB gain was achieved. When the performances are examined considering the Rayleigh fading channel structure, better results are observed for the AWGN channel when the distance between the constellation points in the first sub-carrier is increased. The BER performances are poorer in a Rayleigh fading channel compared to an AWGN channel as expected. While the channel is more stable in direct line of sight (AWGN) environments, the channel behaves more unstable in Rayleigh fading since there is no direct line of sight. The signals that are not in direct line of sight come delayed and weakened due to scattering when reaching the receiver. Therefore, it is expected that similar BER performances could be reached in a Rayleigh fading channel compared to AWGN channel at higher SNR values. After 20dB, such observations could be made in Fig. 17.

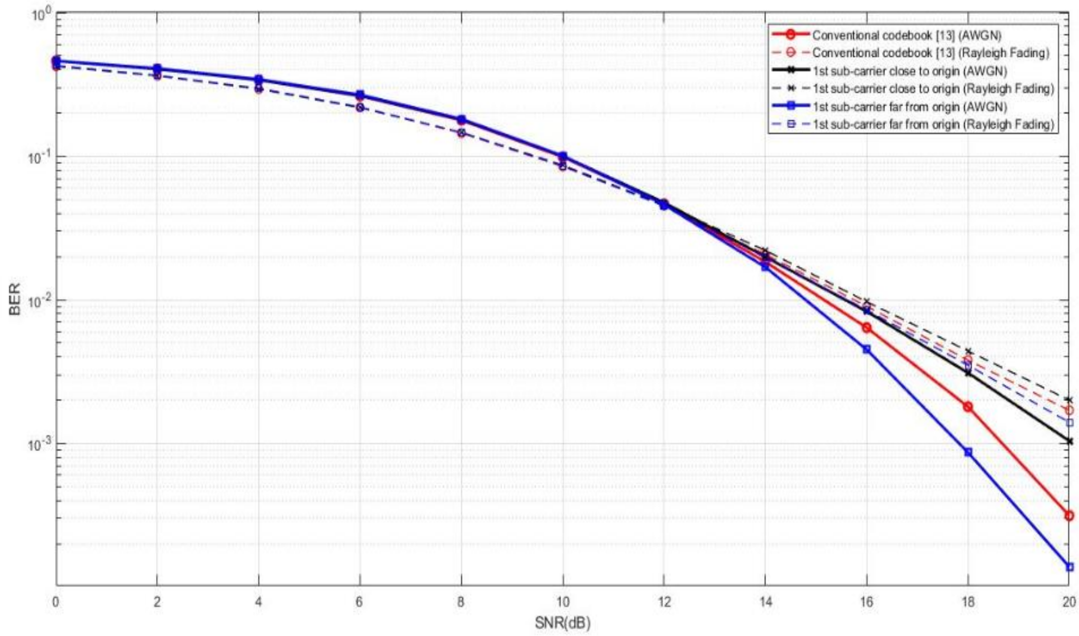

Fig. 17: BER performance when the distance between the points of the constellation sets is changed (Algorithm-1).

In Fig. 18, comparative BER performance results related to increasing the angles between the constellation points obtained with Algorithm 2 have been presented. When the number of users in a sub-carrier was $d_f = 3$, the angles between the constellation sets were set to 60°. When only the angles of the constellation sets in the first sub-carrier were changed, the gain was not achieved compared to the conventional codebook use. When the algorithm is applied for all sub-carriers, approximately 1dB gain is obtained in the high SNR region in an AWGN channel. In Rayleigh fading channel structure, the curve between the points on the first sub-carrier with 60° shows similar performance as in AWGN. The curve, which is 60° between the points in the all sub-carriers, performs worse than AWGN. However, the BER values obtained were close for the first sub-carrier and the conventional codebook cases at the high SNR value. Also, after 20dB, all sub-carriers case is expected to have a cross over and perform better than the conventional case for the Rayleigh fading channel.

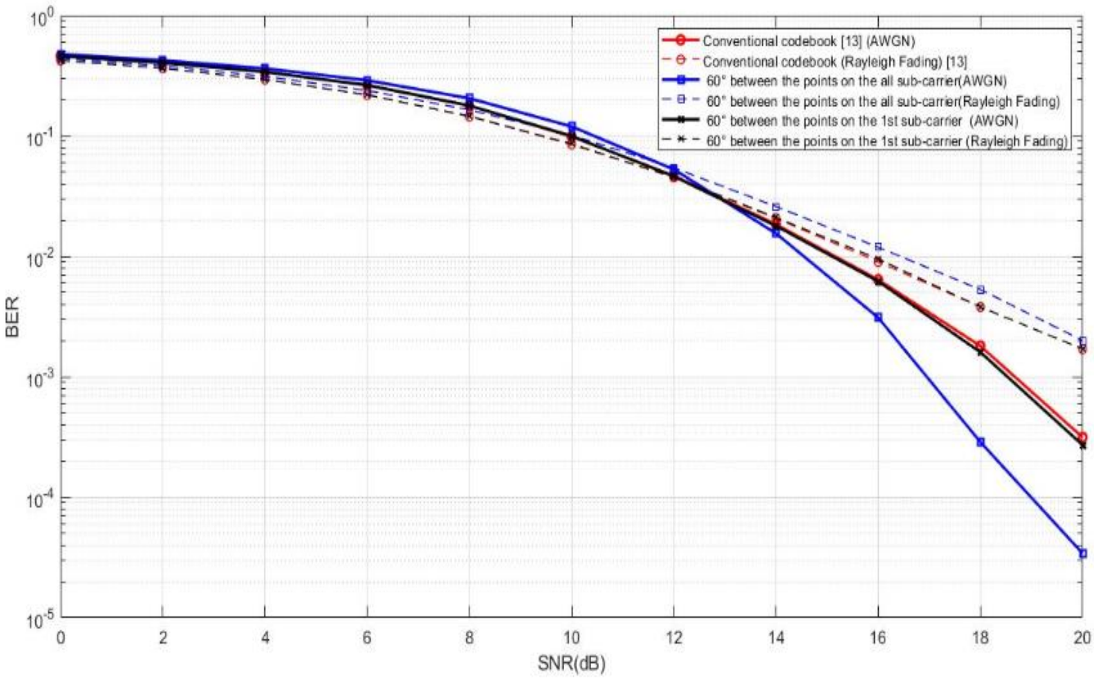

Fig. 18: BER performance when the angle between the constellation sets is changed by rotation (Algorithm-2)

In this thesis, third and fourth methods also target to improve the system performance of the conventional codebook by appropriate modification. With these proposed methods, which are the permutation and new constellation design methods, it has been aimed to determine the performance gain in the high SNR region by determining the point of constellation sets that dominate the BER performance. In Fig. 19, the BER performance of conventional codebook has been presented in AWGN and Rayleigh fading channel and has been compared with the new methods given in Algorithm 3 and Algorithm 4. It shows approximately the same BER value in three curves up to 12dB in AWGN. The other two methods have shown better performance after 12dB compared to the conventional codebook with a gain of about 1.5dB. The new constellation design method, which provides better convergence after 18dB compared to the permutation method, has shown the best BER performance among all. In the Rayleigh fading channel, all curves up to 12dB have close BER values. After 12dB, the new constellation design method, provides better convergence and outperforms the conventional codebook. The permutation method, on the other hand, performs slightly worse than the conventional codebook.

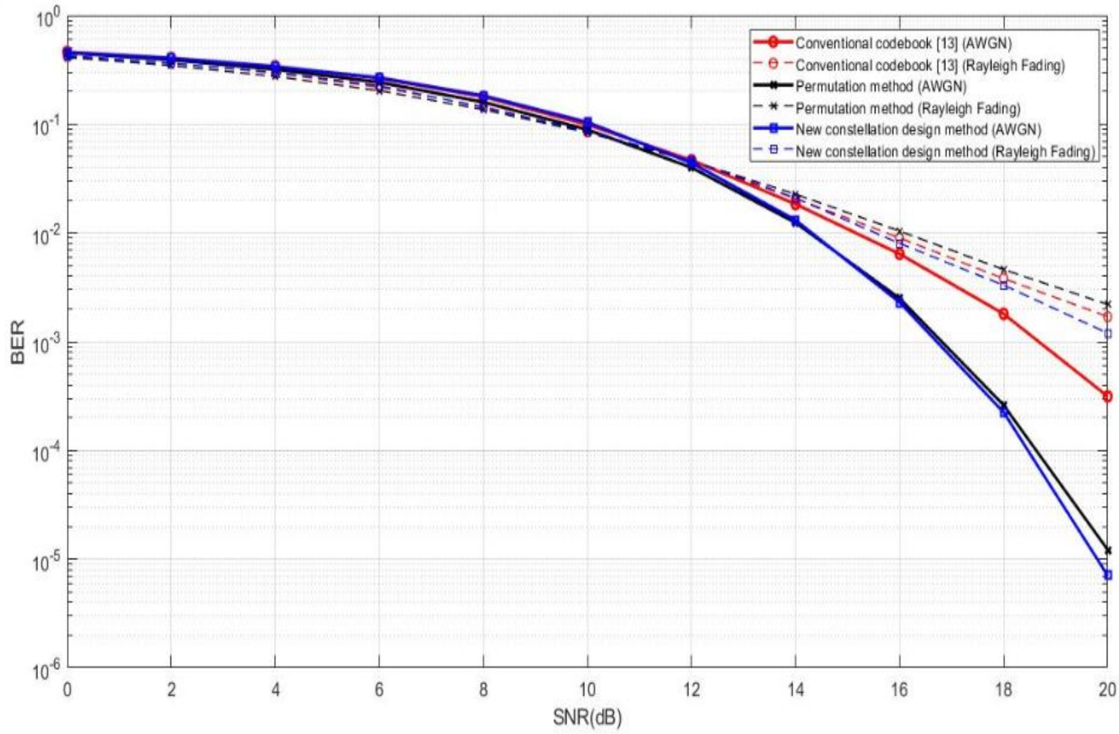

Fig. 19: Comparative BER performance between the permutation and new constellation design method (Algorithm-3 and Algorithm-4)

As a final study, comparative BER performances of the four proposed dessign methods, which outperform the conventional codebook, have been presented. According to the performance outcomes, all four algorithms have been compared to assess which one performs better. The best curves obtained from each algorithm have been presented in Fig. 20. It has approximately the same BER value in all curves up to 12dB. After 14dB, first sub-carrier far from origin curve diverges and performs poorly for the AWGN channel. The other three curves converge and have close BER values up to 18dB. However, at 20dB, the new constellation design method shows better BER performance by making better convergence than the other curves. In the Rayleigh fading channel, all curves up to 12dB have close BER values. After 14dB, first sub-carrier far from origin and new constellation design method curves show better BER performance than the 60° between the points on all sub-carriers and the permutation method curves. As a result, the new constellation design method (Algorithm-4) curve has achieved approximately 1.5dB gain compared to first sub-carrier far from the origin curve (Algorithm-1). Curves in the permutation method (Algorithm-3) and the 60° between the points on all sub-carriers (Algorithm-2) could not perform the desired performances as in the AWGN channel. After 20dB, for these curves, a performance output that is comparable with each other is foreseen as in AWGN.

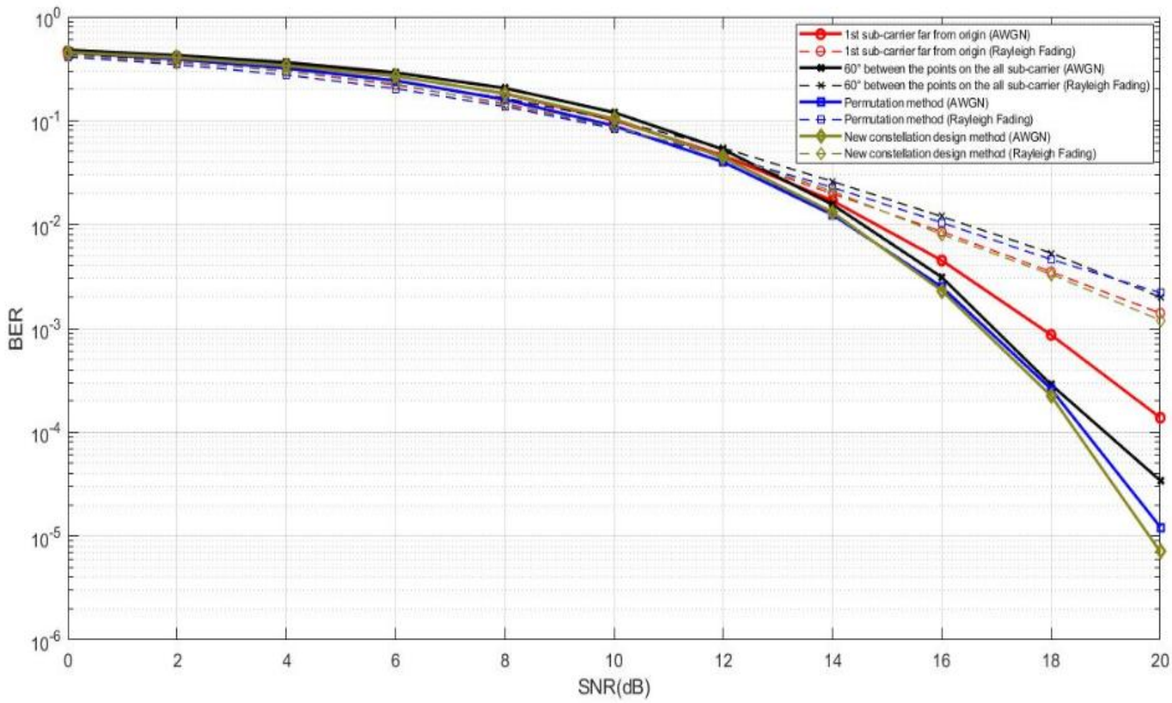

Fig. 20: Comparative BER performances for all four design approaches

6. CONCLUSION AND FUTURE RESEARCH

In this section, conclusion from this thesis will be presented followed by possible future research areas for extension.

6.1 Conclusion

In this study, the conventional SCMA codebook, which is widely used in the literature, has been studied to increase the distances between the constellation set points and to improve SCMA system performance. The codebook is used with four different approaches for increasing the distances between the related constellation set points, the phase-amplitude rotation, the permutation method and the new constellation design method. The BER performance of the SCMA system has been studied in AWGN and Rayleigh fading channels for the conventional and the proposed codebooks.

In the first design method, the distance between the points of the constellation sets has been increased by a certain value while the energy remains constant. The performances of resulting codebooks are compared to the conventional codebook. According to the performance evaluation, by increasing the distance between constellation set points with each other, a better performance has been obtained than the conventional codebook.

In the second design method, the angles of constellation points have been considered. There are three different constellation sets in each sub-carrier in the conventional codebook. The angles between these constellation sets are different from each other. In the second approach, the angles between the constellation sets on the first sub-carrier and all sub-carriers were adjusted to 60° equally and their performances were observed. In terms of performance , when the angle between the constellation sets in the first sub-carrier is 60°, a gain of approximately 1dB was achieved.

In the third and fourth approaches, two new methods, namely permutation and new constellation design methods, have been proposed. Permutation method [37] has been adapted to the conventional codebook that we have considered and the system performance is explored. In the new constellation design method, it is aimed to increase the number of information data in the constellation sets belonging to the users and to provide diversity. According to the performance results, 2dB gain was achieved in the new constellation design method compared to the conventional codebook. Similarly, for the permutation method, approximately 2dB of gain was achieved compared to the conventional codebook. Considering all four proposed methods, the new constellation design showed the best performance for both AWGN and Rayleigh fading channels.

6.2. Future Research

In the future studies, the performance gain of the SCMA system is targeted to increase with new algorithms. With the new methods to be proposed, it is aimed to maximize the gain in both AWGN and Rayleigh fading channels as much as possible. Using the deep learning method, a new codebook design can be made by training the constellation sets in different codebooks in the literature. This new codebook, which will be independent from the conventional codebook, is aimed to achieve better results in terms of performance. When information belonging to different users is transmitted over sub-carriers, MPA algorithm is used in the receiver to determine which user belongs to this information. Users' information is influenced by noise before reaching the receiver. A new multi-step MPA algorithm may be proposed that can sort the users' signal to noise ratio (SNR) to determine the detection order and iterations at each step. In addition, the factor graph can be redesigned to perform uplink user detection before processing the entire MPA. Thus, it is envisaged to reduce the complexity in MPA by reducing the noise, so it is aimed to detect the information of the users at a high success rate at the receiver side.

REFERENCES

[1] P. Gandotra, R. K. Jha, "A survey on green communication and security challenges in 5G wireless communication networks," in Journal of Network and Computer Applications, vol. 96, 2017, pp. 39-61, ISSN 1084-8045, https://doi.org/10.1016/j.jnca.2017.07.002.

[2] M. Rinne, O. Tirkkonen, "LTE, the radio technology path towards 4G," in *Computer Communications*, vol. 33, issue 16, 2010, pp. 1894–1906, ISSN 0140-3664, https://doi.org/10.1016/j.comcom.2010.07.001.

[3] N. Akkari, N. Dimitriou, “Mobility management solutions for 5G networks: Architecture and services,” in *Computer Networks*, vol. 169, Mar. 14, 2020, 107082.

[4] "5G PPP Architecture Working Group View on 5G Architecture (Version 2.0)," 2017-07-18, https://5g- ppp.eu/wp- content/uploads/2017/07/5G- PPP- 5G-Architecture- White- Paper- 2- Summer- 2017 _ For- Public- Consultation.pd.

[5] A. Kakkar, "A survey on secure communication techniques for 5G wireless heterogeneous networks,"in *Information Fusion*, vol. 62, 2020, pp. 89-109, ISSN 1566-2535, https://doi.org/10.1016/j.inffus.2020.04.009.

[6] X. Li , R. Zhou, Y. J. A. Zhang , L. Jiao, Z. Li,” Smart vehicular communication via 5G mmWaves,” in Computer Networks, vol. 172, 2020, 107173 ISSN 1389-1286, https://doi.org/10.1016/j.comnet.2020.107173.

[7] J. G. Andrews et al., "What Will 5G Be?," in *IEEE Journal on Selected Areas in Communications*, vol. 32, no. 6, pp. 1065-1082, June 2014, doi: 10.1109/JSAC.2014.2328098.

[8] J. Zhu, R. Schober and V. K. Bhargava, "Secure Transmission in Multicell Massive MIMO Systems," in *IEEE Transactions on Wireless Communications*, vol. 13, no. 9, pp. 4766-4781, Sept. 2014, doi: 10.1109/TWC.2014.2337308.

[9] X. Liu, D. He, M. Jia, “5G-based wideband cognitive radio system design with cooperative spectrum sensing,” i *Physical Communications*, vol. 25, no. 12, pp. 539–545, 2017

[10] L. Fan, R. Zhao, F. Gong, N. Yang and G. K. Karagiannidis, "Secure Multiple Amplify-and-Forward Relaying Over Correlated Fading Channels," in IEEE Transactions on Communications, vol. 65, no. 7, pp. 2811-2820, July 2017, doi: 10.1109/TCOMM.2017.2691712.

[11] A. Gupta, R.K. Jha, “A survey of 5G network: architecture and emerging technologies,” in *IEEE Access*, vol. 3, pp. 1206 – 1232, 2015, doi: 10.1109/ACCESS.2015.2461602.

[12] L. Ferdouse, S. Erkucuk, A. Anpalagan and I. Woungang, "Energy Efficient SCMA Supported Downlink Cloud-RANs for 5G Networks," in *IEEE Access*, vol. 8, pp. 1416-1430, 2020, doi: 10.1109/ACCESS.2019.2960490.

[13] "Satellite role in 5G Eco-System & Spectrum identification for 5G some perspectives," *5G Radio Technology Seminar. Exploring Technical Challenges in the Emerging 5G Ecosystem*, London, 2015, pp. 1-16, doi: 10.1049/ic.2015.0033.

[14] N. Yunfeng, L. Jiahao, S. Xiaohong, B. Dongdong, " Research on Key Technology in 5G Mobile Communication Network," *2019 International Conference on Intelligent Transportation, Big Data & Smart City (ICITBS)*, Changsha, China, 2019, pp. 199-201, doi: 10.1109/ICITBS.2019.00054.

[15] L. Dai, B. Wang, Y. Yuan, S. Han, C. I and Z. Wang, "Non-orthogonal multiple access for 5G: solutions, challenges, opportunities, and future research trends," in *IEEE Communications Magazine*, vol. 53, no. 9, pp. 74-81, September 2015, doi: 10.1109/MCOM.2015.7263349

[16] M. H. Durak and Ö. Ertuğ, "Compressed Sensing Based Multiuser Detection for Sparse Code Multiple Access," *2019 27th Signal Processing and Communications Applications Conference (SIU)*, Sivas, Turkey, 2019, pp. 1-4, doi: 10.1109/SIU.2019.8806486.

[17] G. B. Satrya and S. Y. Shin, "Security enhancement to successive interference cancellation algorithm for non-orthogonal multiple access (NOMA)," 2*017 IEEE 28th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC)*, Montreal, QC, 2017, pp. 1-5, doi: 10.1109/PIMRC.2017.8292165.

[18] E. M. Eid, M. M. Fouda, A. S. Tag Eldien and M. M. Tantawy, "Performance analysis of MUSA with different spreading codes using ordered SIC methods," *2017 12th International Conference on Computer Engineering and Systems (ICCES)*, Cairo, 2017, pp. 101-106, doi: 10.1109/ICCES.2017.8275286.

[19] Y. Cao, H. Sun, J. Soriaga and T. Ji, "Resource Spread Multiple Access - A Novel Transmission Scheme for 5G Uplink," *2017 IEEE 86th Vehicular Technology Conference (VTC-Fall)*, Toronto, ON, 2017, pp. 1-5, doi: 10.1109/VTCFall.2017.8288412.

[20] Y. Liu, J. Zhong, P. Xiao, M. Zhao, "A novel evidence theory based row message passing algorithm for LDS systems," *2015 International Conference on Wireless Communications & Signal Processing (WCSP)*, Nanjing, 2015, pp. 1-5, doi: 10.1109/WCSP.2015.7341122.

[21] H. Nikopour and H. Baligh, "Sparse code multiple access," *2013 IEEE 24th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC)*, London, 2013, pp. 332-336, doi: 10.1109/PIMRC.2013.6666156.

[22] M. Moltafet, N. M. Yamchi, M. R. Javan and P. Azmi, "Comparison Study Between PD-NOMA and SCMA," in *IEEE Transactions on Vehicular Technology*, vol. 67, no. 2, pp. 1830-1834, Feb. 2018, doi: 10.1109/TVT.2017.2759910.

[23] M. Taherzadeh, H. Nikopour, A. Bayesteh, and H. Baligh, "SCMA Codebook Design," *2014 IEEE 80th Vehicular Technology Conference (VTC2014-Fall)*, Vancouver, BC, 2014, pp. 1–5, doi: 10.1109/VTCFall.2014.6966170.

[24] R. Hoshyar, F. P. Wathan and R. Tafazolli, "Novel Low-Density Signature for Synchronous CDMA Systems Over AWGN Channel," in *IEEE Transactions on Signal Processing*, vol. 56, no. 4, pp. 1616–1626, April 2008, doi: 10.1109/TSP.2007.909320.

[25] L. Yu, X. Lei, P. Fan and D. Chen, “An optimized design of SCMA codebook based on star-QAM signaling constellations,” *2015 International Conference on Wireless Communications & Signal Processing (WCSP)*, Nanjing, 2015, pp. 1-5, doi: 10.1109/WCSP.2015.7341311.

[26] G. Wunder, R. F. H. Fischer, H. Boche, S. Litsyn and J. No, “The PAPR Problem in OFDM Transmission: New Directions for a Long-Lasting Problem,” in *IEEE Signal Processing Magazine*, vol. 30, no. 6, pp. 130–144, Nov. 2013, doi: 10.1109/MSP.2012.2218138.

[27] I. Baig, “A Precoding-Based Multicarrier Non-Orthogonal Multiple Access Scheme for 5G Cellular Networks,” in *IEEE Access*, vol. 5, pp. 19233–19238, 2017, doi: 10.1109/ACCESS.2017.2752804.

[28] Z. Ding, X. Lei, G. K. Karagiannidis, R. Schober, J. Yuan, and V. Bhargava, “A survey on non-orthogonal multiple access for 5G networks: Research challenges and future trends,” in *IEEE Journal on Selected Areas in Communications*, vol. 35, no. 10, pp. 2181–2195, Oct. 2017, doi: 10.1109/JSAC.2017.2725519.

[29] W. Shin, M. Vaezi, B. Lee, D. J. Love, J. Lee and H. V. Poor, "Coordinated Beamforming for Multi-Cell MIMO-NOMA," in *IEEE Communications Letters*, vol. 21, no. 1, pp. 84-87, Jan. 2017, doi: 10.1109/LCOMM.2016.2615097.

[30] K. An, et al., “Hybrid Satellite-Terrestrial Relay Networks with Adaptive Transmission,” in *IEEE Transactions on Vehicular Technology*, vol. 68, no.12, pp. 12448-12452, Dec. 2019, doi: 10.1109/TVT.2019.2944883.

[31] A. Masmoudi, F. Bellili, S. Affes and Ali Ghrayeb, “Maximum Likelihood Time Delay Estimation From Single- and Multi-Carrier DSSS Multipath MIMO Transmissions for Future 5G Networks,” in *IEEE Transactions on Wireless Communications*, vol. 16, no. 8, pp. 4851-4865, Aug. 2017, doi: 10.1109/TWC.2017.2701796..

[32] H. Hosseini, A. Anpalagan, K. Raahemifar and S. Erkucuk, "Wavelet-based cognitive SCMA system for mmWave 5G communication networks," in *IET Communications*, vol. 11, no. 6, pp. 831-836, 20 4 2017, doi: 10.1049/iet-com.2016.0976.

[33] A. Alnoman, S. Erkucuk, A. Anpalagan, "Sparse Code Multiple Access-Based Edge Computing for IoT Systems," in *IEEE Internet of Things Journal*, vol. 6, no. 4, pp. 7152-7161, Aug. 2019, doi: 10.1109/JIOT.2019.2914570.

[34] S. M. R. Islam, N. Avazov, O. A. Dobre, K.S. Kwak, “Power-Domain Non-Orthogonal Multiple Access (NOMA) in 5G Systems: Potentials and Challenges,”in *IEEE Communications Surveys & Tutorials*, vol. 19, no. 2, Secondquarter 2017, doi: 10.1109/COMST.2016.2621116.

[35] F.Kiraci, E.Bardakci, Y. Sadi, S.Erkucuk, "The Effect of Codebook Design on the Conventional SCMA System Performance," *28th Signal Processing and Communications Applications Conference*, (to appear) Oct. 2020.

[36] Huawei, The 1st 5G Algorithm Innovation Competition SCMA. Altera University Program, 2015.

[37] M. Kulhandjian and C. D'Amours, "Design of permutation-based sparse code multiple access system," *2017 IEEE 28th Annual International Symposium on*

Personal, Indoor, and Mobile Radio Communications (PIMRC), Montreal, QC, 2017, pp. 1-6, doi: 10.1109/PIMRC.2017.8292576.

[38] L. Dai, B. Wang, Z. Ding , Z. Wang, Sheng Chen and L. Hanzo," A Survey of Non-Orthogonal Multiple Access for 5G," in *IEEE Communications Surveys & Tutorials*, vol. 20, no. 3, pp. 2294-2323, thirdquarter 2018, doi: 10.1109/COMST.2018.2835558.

[39] A. W. Scott; R. Frobenius, "Multiple access techniques: FDMA, TDMA, and CDMA," in *RF Measurements for Cellular Phones and Wireless Data Systems*, IEEE, 2008, pp. 413–429, doi: 10.1002/9780470378014.ch30.

[40] H. Li, G. Ru, Y. Kim, and H. Liu, "OFDMA capacity analysis in MIMO channels," *IEEE Transactions on Information Theory*, vol. 56, no. 9, pp. 4438–4446, Sept. 2010, doi: 10.1109/TIT.2010.2054710.

[41] Y. Chen et al., "Toward the Standardization of Non-Orthogonal Multiple Access for Next Generation Wireless Networks," in *IEEE Communications Magazine*, vol. 56, no. 3, pp. 19-27, March 2018, doi: 10.1109/MCOM.2018.1700845.

[42] M. Moltafet, N. Mokari, M. R. Javan, H. Saeedi and H. Pishronik, "A New Multiple Access Technique for 5G: Power Domain Sparse Code Multiple Access (PSMA)," in *IEEE Access*, vol. 6, pp. 747-759, 2018, doi: 10.1109/ACCESS.2017.2775338.

[43] R. Hoshyar, R. Razavi and M. AL-Imari, "LDS-OFDM an Efficient Multiple Access Technique," *2010 IEEE 71st Vehicular Technology Conference*, Taipei, 2010, pp. 1-5, doi: 10.1109/VETECS.2010.5493941.

[44] Z. Yuan, G. Yu, W. Li, Y. Yuan, X. Wang and J. Xu, "Multi-User Shared Access for Internet of Things," *2016 IEEE 83rd Vehicular Technology Conference (VTC Spring)*, Nanjing, 2016, pp. 1-5, doi: 10.1109/VTCSpring.2016.7504361.

[45] X. Dai et al., "Successive interference cancelation amenable multiple access (SAMA) for future wireless communications," *2014 IEEE International Conference on Communication Systems*, Macau, 2014, pp. 222-226, doi: 10.1109/ICCS.2014.7024798.

[46] M. Dabiri, H. Saeedi, "Dynamic SCMA Codebook Assignment Methods: A Comparative Study," *IEEE Communication Letters*, vol. 22, no. 2, pp. 364 – 367, Feb. 2018, doi: 10.1109/LCOMM.2017.2764469.

[47] Y. Zhou, Q. Yu. W. Meng, and C. Li, "SCMA codebook design based on constellation rotation," *2017 IEEE International Conference on Communications (ICC)*, Paris, 2017, pp. 1 – 6, doi: 10.1109/ICC.2017.7996395.

[48] M. Vameghestahbanati, I. D. Marsland, R. H. Gohary and H. Yanikomeroglu, "Multidimensional Constellations for Uplink SCMA Systems—A Comparative Study," in *IEEE Communications Surveys & Tutorials*, vol. 21, no. 3, pp. 2169-2194, thirdquarter 2019, doi: 10.1109/COMST.2019.2910569.

[49] S. Liu, J. Wang, J. Bao and C. Liu, "Optimized SCMA Codebook Design by QAM Constellation Segmentation With Maximized MED," in *IEEE Access*, vol. 6, pp. 63232-63242, 2018, doi: 10.1109/ACCESS.2018.2876030.

[50] W. B. Ameur, P. Mary, M. Dumay, J. F. Hélard, J. Schwoerer, "Performance study of MPA, Log-MPA and MAX-Log-MPA for an uplink SCMA scenario," 2019 *26th International Conference on Telecommunications (ICT)*, Hanoi, Vietnam, 2019, pp. 411-416, doi: 10.1109/ICT.2019.8798841.

[51] J. Bao, Z. Ma, Z. Ding, G. K. Karagiannidis, Z. Zhu, “On the Design of Multiuser Codebooks for Uplink SCMA Systems,” in *IEEE Communications Letters*, vol. 20, no.10, pp. 1920 – 1923, Oct. 2016, doi: 10.1109/LCOMM.2016.2596759.

[52] M.Alam and Q. Zhang, “Performance study of SCMA codebook design”, *IEEE Wireless Communications and Networking Conference (WCNC),* San Francisco, CA, 2017, pp 1-5, doi: 10.1109/WCNC.2017.7925767.

[53] F. Tekçe, E. Çatak, U. E. Ayten, and L. Durak-Ata, “The effect of codebook design on the BER performance of MTC systems employing SCMA,” *2018 26th Signal Processing and Communications Applications Conference (SIU)*, Izmir, 2018, pp. 1-4, doi: 10.1109/SIU.2018.8404779.

[54] T. Metkarunchit, “ SCMA Codebook Design Base on circular-QAM,” *2017 Integrated Communications Navigation and Surveillance Conference (ICNS),* Herndon, VA, 2017, pp. 3E1-1-3E1-8, doi: 10.1109/ICNSURV.2017.8011917.

[55] J. Boutros, E. Viterbo, C. Rastello, and J.-C. Belfiore, “Good lattice constellations for both rayleigh fading and gaussian channels,” *IEEE Transactions on Information Theory,* vol. 42, no. 2, pp. 502–518, Mar.1996, doi: 10.1109/18.485720.

[56] S. Zhang, B. Xiao, K. Xiao, Z. Chen, and B. Xia, “Design and Analysis of Irregular Sparse Code Multiple Access,” I*EEE International Conference on Wireless Commun. & Signal Process. (WCSP 2015),* Nanjing, China, pp. 1-5, Oct. 2015.

[57] M. Alam and Q. Zhang, "Designing optimum mother constellation and codebooks for SCMA," *2017 IEEE International Conference on Communications (ICC),* Paris, 2017, pp. 1-6, doi: 10.1109/ICC.2017.7996539.

[58] P. Larsson, "Golden Angle Modulation," in *IEEE Wireless Communications Letters*, vol. 7, no. 1, pp. 98-101, Feb. 2018, doi: 10.1109/LWC.2017.2756630.

[59] D. Cai, P. Fan, X. Lei, Y. Liu and D. Chen, "Multi-Dimensional SCMA Codebook Design Based on Constellation Rotation and Interleaving," *2016 IEEE 83rd Vehicular Technology Conference (VTC Spring)*, Nanjing, 2016, pp. 1-5, doi: 10.1109/VTCSpring.2016.7504356.

[60] Y. Zhou, Q. Yu, W. Meng and C. Li, "SCMA codebook design based on constellation rotation," *2017 IEEE International Conference on Communications (ICC)*, Paris, 2017, pp. 1-6, doi: 10.1109/ICC.2017.7996395.

[61] J. Bao, Z. Ma, M. A. Mahamadu, Z. Zhu and D. Chen, "Spherical Codes for SCMA Codebook," *2016 IEEE 83rd Vehicular Technology Conference (VTC Spring)*, Nanjing, 2016, pp. 1-5, doi: 10.1109/VTCSpring.2016.7504489.

[62] H. Yan, H. Zhao, Z. Lv and H. Yang, "A top-down SCMA codebook design scheme based on lattice theory," *2016 IEEE 27th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC)*, Valencia, 2016, pp. 1-5, doi: 10.1109/PIMRC.2016.7794680.

[63] L. Yu, P. Fan, D. Cai and Z. Ma, "Design and Analysis of SCMA Codebook Based on Star-QAM Signaling Constellations," in *IEEE Transactions on Vehicular Technology*, vol. 67, no. 11, pp. 10543-10553, Nov. 2018, doi: 10.1109/TVT.2018.2865920.

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