Journal of Engg. Research Vol.10 No. (4A) pp. 132-152 DOI: 10.36909/jer.10875

Code domain non orthogonal multiple access schemes for 5G and beyond communication networks: A review

Aasheesh Shukla*, **, Manish Kumar* and Vinay Kumar Deolia

Department of Electronics and Communication, GLA, University, Mathura. India
*** Corresponding Author: aasheesh.shukla@gla.ac.in*

Submitted ***:*** 18/06/2020
Revised ***:*** 04/08/2021
Accepted ***:*** 14/08/2021

ABSTRACT

Future communication networks may encounter various issues in order to facilitate heavy heterogeneous data traffic and large number of users; therefore, more advanced multiple access (MA) schemes are being developed to meet the changing requirements. The research space on making more robust MA scheme is continuously increasing, so it becomes significant to analyze the various schemes to determine the appropriate MA scheme for 5G networks. Therefore, in this paper, the comprehensive overview of the most popular and recent MA schemes is presented for 5G networks. This paper mainly classifies the MA techniques in orthogonal MA (OMA) and various types of non-OMA (NOMA) techniques. Specifically, we introduce the rate splitting multiple access (RSMA) and interleave division multiple access (IDMA). Further, close attention is paid to NOMA family, including code-domain NOMA (e.g., sparse code multiple access (SCMA)) and power-domain NOMA. Above all, from this exploration, the opportunities and challenges could be notified in MA schemes, and further, the optimum MA technique can be pointed out among the discussed MA schemes for 5G and beyond communication networks.

Keywords: SCMA; IDMA; NOMA; Code domain NOMA; Power domain NOMA.

INTRODUCTION

High speed, better quality of services, high throughput, and low latency are some of few attributes for fifth generation (5G) and future wireless communication networks. Recent research activities include many new applications, such as massive machine type communications (mMTC), enhanced mobile broadband (eMBB), ultra-reliable and low-latency communications (URLLC), and enhanced vehicle-to-everything (eV2X) communications. All these scenarios required massive connectivity, better system throughput, and improved spectrum utilization. To improve spectrum utilization, many multiple access (MA) schemes have been proposed in time, frequency, and space domain. Broadly, MA schemes can be classified into two categories, namely, orthogonal multiple access (OMA) and nonorthogonal multiple access (NOMA) scheme. In OMA schemes, all the users are orthogonal to each other, and hence, interference among users could be minimized. Further, OMA can be considered as a parent MA scheme for all previous and current MA techniques. In second generation (2G) of wireless communication system, time-division multiple access (TDMA) and frequency-division multiple access (FDMA) were popular (S. M. R. Islam,2017, W. Shin et al., 2017, L. Dai et al., 2015, Z. Ding et al., 2017).

In TDMA, many users utilized the whole spectrum in certain assigned time slots, whereas, in FDMA, users could communicate through assigned frequency channels. Underutilization of frequency spectrum in FDMA and synchronization in TDMA were major concerns with these MA schemes. In 3G systems, code division multiple access (CDMA) and, in 4G communication system, orthogonal frequency division multiple access (OFDMA) became popular. For all these MA schemes, the orthogonality in resource blocks is the key issue in time, frequency, and code domains; hence, the interference among users is minimum, and detection is relatively simple. Further, these MA schemes can be considered in the category of OMA scheme. However, only limited number of users can be accommodated in OMA schemes due to the limitations in orthogonality among resource blocks. In opposition to OMA, for massive connectivity of users, the NOMA schemes have been proposed. NOMA does not require orthogonality among resources; it simply offers multiplexing within either of the frequency, time, or code domain and simultaneously offers many advantages such as improved spectral efficiency (SE), higher cell throughput, and low latency. NOMA schemes can be broadly studied in two categories, namely, power domain NOMA (PD-NOMA) and code domain NOMA (CD-NOMA). SCMA is also a recently proposed code domain NOMA scheme that can offer better spectral efficiency. In SCMA, code domain layers can be allocated to distinguish the users without the prior knowledge of channel state information (CSI). Further, space division multiple access (SDMA) has also been suggested, which utilizes the linear precoding to differentiate the multiple users in the spatial domain and consider any residual multiuser interference as noise, whereas PD-NOMA relies on superposition coding with successive interference cancellation (SIC). To combat the limitations of these schemes, a new multiple access scheme is proposed, namely, rate splitting multiple access (RSMA), which is the intermediate path between two extremes, that is, SDMA and PD-NOMA. In this article, a comprehensive overview of existing MA schemes is provided, which are suitable for 5G and beyond networks (Y. Liu, et al., 2016, Xu, C., 2017, A. Dobre, 2017, H. V. Poor et al., 2014, G. K. Karagiannidis, 2016), Almutairi, Ali F., Mishal Al-Gharabally, and Ayed A. Salman (2021).

To the best of our knowledge, existing surveys in this area focus on NOMA; however, this survey includes a more complete introduction of different OMA and NOMA schemes with special attention towards newly developed MA schemes, such as RSMA, IDMA, and SCMA. Additionally, the simulation results and comparative analysis have also been presented to justify the optimum MA scheme. Further, it is expected that this paper could guide the authors who wish to carry out research in the development of new and robust MA schemes for future communication networks. The rest of this article is organized as follows. In Section II, popular MA candidates of OMA up to 4G networks are introduced. In Section III, PD- NOMA schemes are discussed, and code-domain NOMA is elaborated in section IV. NOMA in other multiplexing domains has also been presented in Section V. In Section VI, comparative analysis of different MA schemes has been discussed, and finally, Section VI concludes this article.

ORTHOGONAL MULTIPLE ACCESS

In the developments of MA schemes, the pioneer contributions of ‘Shannon’ were crucial for modern wireless communication. The exponential growth of the user needs to facilitate successful connectivity, and in order to achieve this goal, many MA schemes are designed. In the first generation (1G), FDMA were used. As the digital communication (2G) arises, TDMA was found to be more suitable, and in 3G, the CDMA technique emerged. With the dramatic increase in number of users in 4G. a more robust and efficient scheme has been suggested, namely, orthogonal frequency division multiple access (OFDMA). OFDMA can be considered as multiple access/multiplexing scheme that facilitates users by multiplexing operation in uplink as well as downlink channel. In comparison to traditional CDMA, the OFDMA can provide higher reverse link capacity. For two user networks, the capacity region in OFDMA can be convex bounded by

$$R_1 < W \log_2(1+\frac{P_1}{P_n}) \tag{1}$$

$$R_2 < W \log_2(1+\frac{P_2}{P_n}) \tag{2}$$

where P_1 and P_2 are the received power to the users, and P_n is the noise. In 4G communication network, OFDMA offered many advantages such as scalability, robustness to multipath, and downlink multiplexing, and further, this scheme can be enhanced for multiple input and multiple output (MIMO). Along with several advantages, there are some challenges that motivate researchers for the designing of more efficient MA schemes. Intercarrier interference (ICI), high peak to average power ratio (PAPR), and frequency synchronization were some crucial issues to be resolved in OFDMA (G. K. Karagiannidis, 2016).

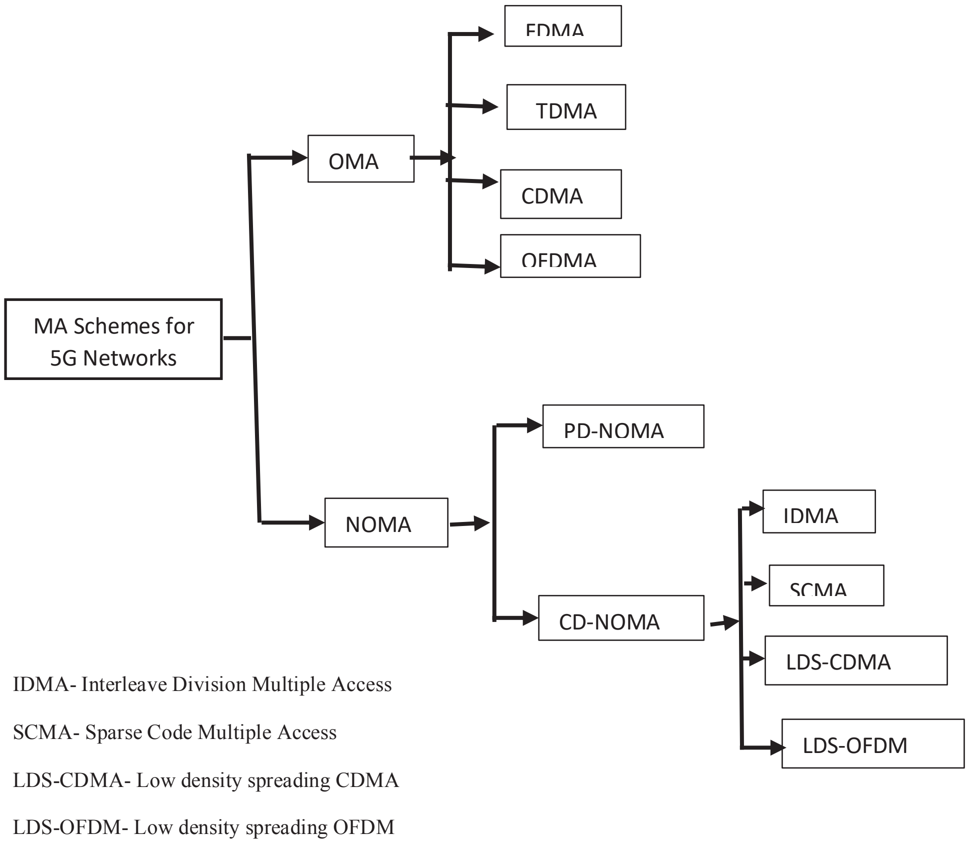

Figure 1. Classification of Multiple access schemes of 5G networks.

NONORTHOGONAL MULTIPLE ACCESS

In traditional OMA schemes, interference can be mitigated due to the use of orthogonal resources. However, only limited number of users can access the channel in OMA schemes. So, for massive user connectivity, the NOMA design can be helpful, in which nonorthogonal resources have been utilized to distinguish different users. Latest research also revealed that OMA always cannot attain the maximum rate, while NOMA has the capacity to achieve the multiuser capacity with the help of rate splitting and time sharing. Furthermore, due the channel dispersing response, the time domain signals of OMA schemes got smeared in the channel. For the simple comparison between NOMA and OMA, the adaptive TDMA and fixed length TDMA can be considered as OMA, and NOMA is based on successive interference cancellation (SIC). Fig. 2 considers the sum rate analysis of OMA add NOMA scheme under equal energy control (EEC). In EEC, the power level may be different for users; however, the energy per frame is the same for all users.

The sum rate in Fig. 2 clearly depicts that the sum-rate performance of NOMA is better than that of TDMA. Along with better sum rate performance, the NOMA scheme can also mitigate the distortions with the help of powerful multiuser detectors. Further, the key features of NOMA can be summarized as follows:

- Low Latency: in the uplink transmission in NOMA, there is no requirement of scheduling the request of user to base station. Hence, it reduces the transmission latency.
- Better SE: NOMA exhibits higher spectral efficiency due to the availability of all resources (frequency, time, and code) to each user.
- Massive Connectivity: with the ability to support multiple users in a single resource block, NOMA has the potential to support massive connectivity.

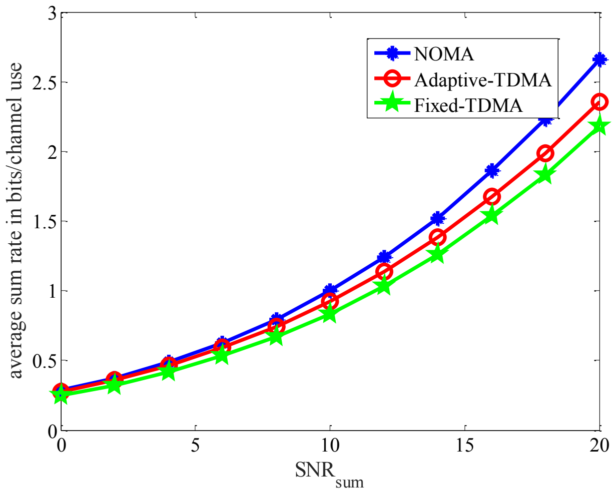

Figure 2. Achievable Sum rate of NOMA and OMA schemes under EEC. NOMA is based on SIC and Adaptive TDMA and Fixed length TDMA is considered as OMA (Jayashree, L. S. et al., 2021).

Except the given prominent advantages, many other attributes of NOMA can be further investigated, which make NOMA as a potential candidate for 5G and beyond networks. Further, NOMA can be classified in two types, namely, power domain NOMA and code domain NOMA (Jayashree, L. S. et al., 2021).

POWER DOMAIN NOMA

In the concept of power domain NOMA, multiple users can be served by using same time slot or the same spreading code and multiple accessing can be achieved through the different power allocation to different users.

In PD-NOMA, the users having higher channel gains are referred to as 'strong users' and poor channel gains as 'weak users.' The strong user subtracts the signal of weak user by using successive interference cancellation (SIC) and then detects its own signal. The weak user considers the signal of strong user as interference noise to detect its own signal. Figure 2 illustrates the basic power domain NOMA downlink communication system, which is popularly known as multiuser superposition transmission (MUST) in which one base station (BS) serves two users simultaneously. Assume that the respective channel coefficient is given by h_1 and h_2. According to NOMA concept, the channel coefficients are related as $|h_1| \geq |h_2|$, and it is clear that weak user is assigned more power, whereas strong user will get less power. So, BS choose the power allocation coefficient such as β_1 β_2 which are related as $\beta_1^2 + \beta_2^2 = 1$ given that $\beta_2 \geq \beta_1$. User 2 decodes its signal by treating user 1 as noise, which results in an achievable rate of $\log_2\left(1 + \frac{|h_2|^2 \beta_2^2}{|h_1|^2 \beta_1^2 + 1/\eta}\right)$ and simultaneously, user 1 subtracts the user 2 signal using SIC to decode the signal and yield the achievable rate of $\log_2\left(1 + \eta |h_1|^2 \beta_1^2\right)$, where η represents transmitted SNR. The spectral efficiency (SE) gain of PD-NOMA over OMA can also be justified with the help of achievable rates. Consider the high SNR scenario ($\eta \to \infty$). According to fig. 1, the sum rate of NOMA can be written as

$$\log_2\left(1 + \frac{|h_2|^2 \beta_2^2}{|h_1|^2 \beta_1^2 + 1/\eta}\right) + \log_2\left(1 + \eta |h_1|^2 \beta_1^2\right) \tag{3}$$

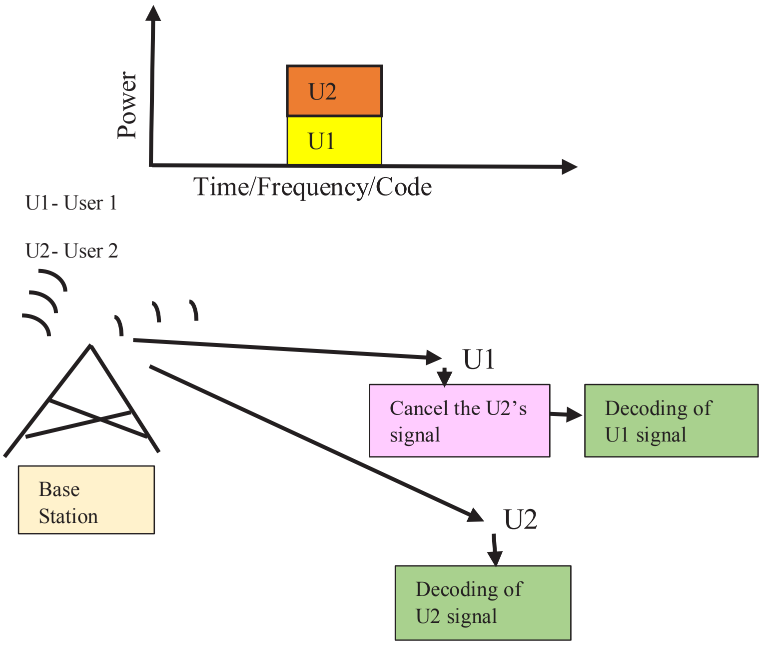

Figure 3. Basic NOMA principle in downlink communication with one base station two users.

With certain approximations, equation (3) can be further elaborated as follows:

$$\begin{aligned}&\approx \log_2\left(1+\frac{\beta_2^2}{\beta_1^2}\right)+\log_2\left(\eta|h_1|^2\beta_1^2\right)\\&=\log_2\left(\eta|h_1|^2\right)\end{aligned} \tag{4}$$

On the other hand, the achievable rates of OMA system can be written as

$$\begin{aligned}&\frac{1}{2}\log_2\left(1+\eta|h_2|^2\right)+\frac{1}{2}\log_2\left(1+\eta|h_1|^2\right)\\&\approx\frac{1}{2}\log_2\left(1+\eta|h_1|^2\right)\end{aligned} \tag{5}$$

Equations (4) and (5) clearly justify the spectral efficiency gain of NOMA over OMA. It is interesting to note that although PD-NOMA allocates more power to the weak user, still the QoS of weak user cannot be guaranteed. The cognitive radio and NOMA can be jointly proposed to meet the target QoS of users (K.-S. Kwak et al., 2017, Kader, Md Fazlul. 2020).

COGNITIVE RADIO NOMA

In cognitive radio (CR) NOMA, the power allocation is done by ensuring to meet the target QoS of users. The BS provides the power to the users according to NOMA principle, specially, the weak user; that is, the user in poorer channel condition is treated as a primary user. The data rate condition in CR-NOMA can be expressed as

$$\log_2\left(1+\frac{|h_2|^2\beta_2^2}{|h_1|^2\beta_1^2+1/\eta}\right)\geq r_2 \tag{6}$$

where r_2 is the target data rate for user 2. The power allocation policy can be described as follows:

$$\beta_2^2=\min\left\{1,\left(\frac{(|h_2|^2+1/\eta)(2^{r_2}-1)}{|h_2|^2\,2^{r_2}}\right)\right\} \tag{7}$$

The outage probability of CR-NOMA is also calculated in [47] for two-user downlink system. Energy efficiency for multiantenna system is expressed in Awasthi, V. and Av, B. (2021).

CODE DOMAIN NOMA

As discussed, the plethora of NOMA has been subdivided in two categories. PD-NOMA is already discussed in the previous section. The other multiplexing domain can be based on signature code, which is named as code domain

NOMA. This scheme can support a large number of user's transmissions in the same time/frequency resource block by assigning different signature codes to different users. An interesting feature associated with code domain NOMA is that it can perform better in power balanced scenarios, when all the signature sequences are unique. However, the code domain NOMA has received less attention of the researchers in comparison to PD-NOMA because the detection algorithms used in CD-NOMA are complex and nonlinear in nature such as message passing algorithm (MPA), maximum likelihood (ML), and a maximum posteriori (MAP) detection. In this section, different available code domain NOMA schemes were explored. Existing code domain NOMA solutions include low density spreading CDMA (LDS-CDMA), LDS-OFDM, sparse code multiple access (SCMA), and interleave division multiple access (IDMA).

LDS-CDMA

In this scheme, the signature sequences are provided to each user and are fully transparent to receiver. Fig. 4 shows the LDS structure to generate the spreading sequences. Assume that the length of spreading sequence (chip length) is N . In conventional CDMA, all the N chips are non-zero and optimized on the basis of auto/cross correlation, whereas in the proposed LDS structure, the N chips are arranged in such a way that each user spreads their data over a small number of chips d_v .

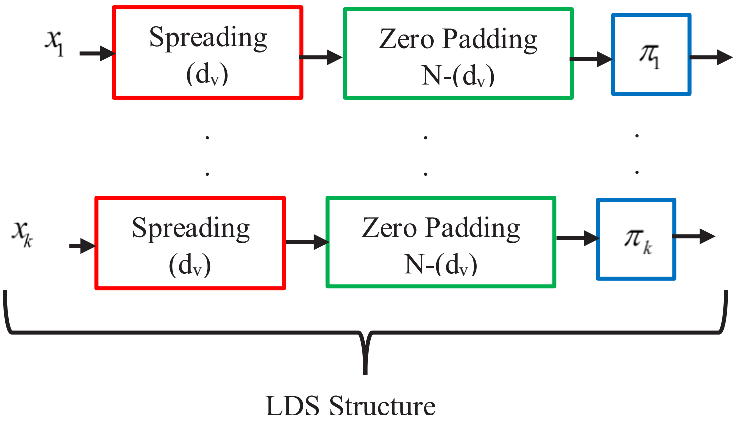

Figure 4. LDS structure for signature sequence generation.

Further, after doing zero padding, the chips are interleaved in a way such that resultant spreading sequence matrix becomes sufficient sparse. Now, the resultant spreading sequence will have d_v non-zero values and $N-d_v$ zero values. Chip level soft-in soft-out multiuser detection using message passing algorithm is used for detecting the LDS spreading sequence. The performance evaluation of LDS based CDMA communication system is presented in Ali Imran (2019), and the simulation results show obvious improvement in the performance of LDS- CDMA over conventional CDMA.

LDS-OFDM

The characteristics of LDS-OFDM system are very similar to the LDS-CDMA system, except that the spreading sequences can be mapped into the multiple subcarriers. The low complex message passing algorithm (MPA) based detection can be used at receiver. Due to the use of multicarrier transmission, LDS- OFDM is suitable for wideband communication (Shukla, Aasheesh. 2021).

SCMA

Sparse code multiple access has been proposed in Chen, Yen-Ming, and Jian-Wei Chen (2020), which can be considered as a modified and improved version of LDS-CDMA. As shown in fig. 5, in SCMA, the bit to QAM mapper and spreading are combined, and incoming message bits are directly mapped to SCMA codebook set.

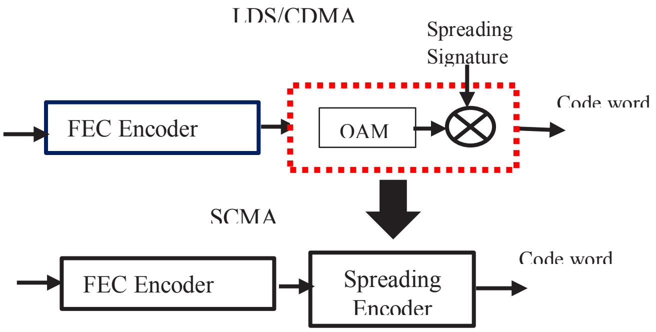

Figure 5. Merging of QAM and spreading to generate the SCMA code-word.

SCMA is having certain characteristics, which can be listed as follows:

- Bits are directly mapped to multidimensional code-word from a predefined multidimensional codebook.
- Users are distinguished with the help of code words and hence achieved multiple access.
- MPA multiuser detection scheme is used at receiver with moderate complexity.

Table 1. SCMA Vs LDS.

	SCMA	**LDS**
Multiple Access	Used predefined Codebook	Signature domain
Sparse	Sparse code-words	Low density signatures
Coding	Bits mapped to multidimensional complex code-words	Bits are carried by QAM symbols
Receiver	Code based MPA	Symbol based MPA

SCMA SYSTEM MODEL

In SCMA, the incoming data stream of length n bits is subdivided into a certain number of blocks with the length $\ell = \log_2 n$. Further, each block is mapped to k-length vector code word, selected from predefined multidimensional SCMA code-book set. If the total number of available resources (subcarrier) is K and N is the total subcarriers used by each user $\forall(1 \leq N \leq K)$, then the number of users, who can share all available resources, will be $j_{user} = \binom{K}{N}$. Furthermore, the factor graph approach is used to allocate the available resources to all users (j_{user}). The factor graph matrix is denoted as $\mathbf{F}_{(\mathbf{K},\mathbf{j}_{\mathbf{user}})} = [\mathbf{f}_1\ \mathbf{f}_2\ \mathbf{f}_3 \ldots \mathbf{f}_{\mathbf{j}_{\mathbf{user}}}]$, where $\mathbf{f}_{user}$ is denoted as indicating vector. In matrix, the subcarrier frequency is represented by each row, and column indicates the user. Further, achieving multiple access through SCMA offers many advantages such as massive connectivity, low overhead, and high capacity. The sparse nature of codebook reduces layer interference. SCMA can be treated as an important tool for low latency and small overhead. Many advanced receivers can be applied to SCMA, among them is the SIC based receiver, which is simple; however, this scheme does not perform well when SNR difference between data and layer is not obvious. Message passing algorithm (MPA) based receiver can also be used in SCMA. This scheme jointly decodes the data/layer of all users. The complexity of MPA receiver is very little in comparison to traditional ML detector. Moreover, MPA based receiver also does not pay attention to the SNR difference at receiver, and it also offers robustness to channel correlations between users. Further, to meet the advantages of both schemes, the joint SIC-MPA receiver has been proposed. The SIC-MPA receiver is close to ML detection and robust to channel variations. The complexity of this receiver is also moderate. Moreover, the expectation propagation algorithm (EPA) is one more option as low complexity receiver. The complexity of EPA receiver varies linearly with modulation order. Basically, EPA is the approximate Bayesian inference method in machine learning for estimating posterior distribution through distribution projection. Mathematically, the distribution projection can be written as

$$\mathrm{Proj}_{\Phi}(\mathrm{p}) = \arg\min_{q \in \Phi} D(p \| q) \tag{8}$$

where the projection of particular distribution p is defined in some distribution set Φ and $D(p\|q)$ is defined as Kullback-Leibler divergence (as per equation [8]). The different complexity orders of different SCMA receivers are summarized in Table 2. Here, S is spread length, the number of receiver antennas is denoted as N_{Rx}, and the number of iterations in the simulation experiments is taken as N_{iter}. N_{UE} is the number of users, and $M_p$is the number of projections.

Table 2. Complexity orders of different receivers in SCMA.

Receivers	Complexity order
MMSE-SIC	$\mathrm{O}(\mathrm{S}^3 \mathrm{N}_{\mathrm{Rx}}^3 \mathrm{N}_{\mathrm{UE}})$
Full MPA	$\mathrm{O}(\mathrm{N}_{\mathrm{Rx}} \mathrm{N}_{\mathrm{iter}} \sum_{\mathrm{i}=1}^{\mathrm{S}} \mathrm{M}_{\mathrm{p}}^{\mathrm{d(i)}})$
SIC-MPA	$\mathrm{O}(\mathrm{S} \mathrm{N}_{\mathrm{Rx}} \mathrm{N}_{\mathrm{iter}} \mathrm{M}_{\mathrm{p}}^{\mathrm{d_f}})$
EPA	$\mathrm{O}(\mathrm{S} \mathrm{N}_{\mathrm{Rx}} \mathrm{N}_{\mathrm{iter}} \mathrm{M}_{\mathrm{p}} \mathrm{d}_{\mathrm{f}})$

The performance of SCMA can be shown with the help of link level solution. In the simulation experiment (fig. 6), it is clearly depicted that SCMA outperforms LDS-CDMA (Chen, Yen-Ming, and Jian-Wei Chen, 2020; L. Lu et al., 2015).

IDMA

Interleave division multiple access (IDMA) is recently considered as a potential candidate in the field of code domain NOMA. It can be considered as a special case of direct sequence-code division multiple access (DS-CDMA).

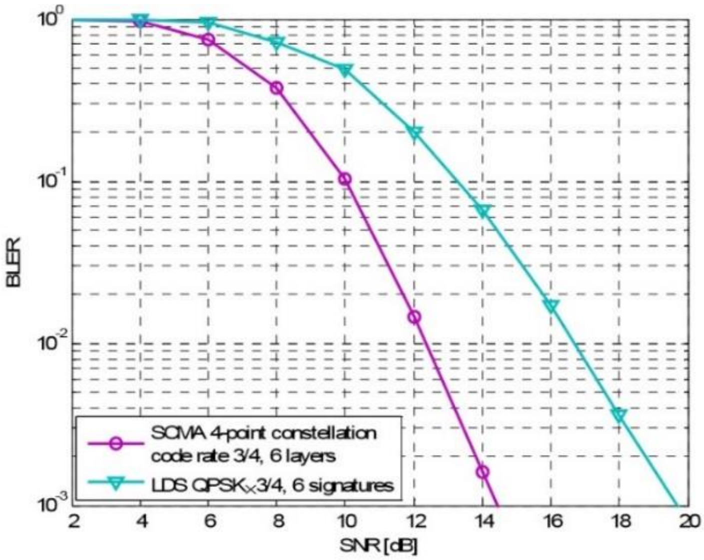

Figure 6. SNR performance of SCMA and LDS-CDMA [L. Lu et al., 2015].

Unlike CDMA system, the user specific spreading sequences are not used in IDMA to distinguish the users. Instead, the whole bandwidth is devoted to forward error correction code (FEC) that results in a very low-rate code as compared to CDMA system. Further, as a unique feature, user specific interleavers are used to separate users in IDMA. Originally, IDMA was proposed with the help of sparse graph scheme (Ping, L., Liu, L., Wu, K. and Leung, W.K., 2006).

IDMA SYSTEM MODEL

For simplicity, the SISO-IDMA system can be considered. Let $\{\mathrm{d_k}\}$ be the data and $\mathbf{c_k} = \{\mathrm{c_k}(j)\}$ be the coded bits of k^{th} user of length j. Assume BPSK modulation, i.e., $c_k(j) \in [-1,+1]$ for transmission. Hence, a transmitted symbol with BPSK modulation can be expressed as

$$x_k(j) = \sqrt{p_k}\, c_k(j'') \tag{9}$$

where j'' is defined with the help of user specific chip level interleaver. p_k is the power control parameter. The received signal at the receiver $y(j)$ can be given as

$$y(j) = \sum_{k=1}^{K} h_k x_k + n(j) \tag{10}$$

where h_k is the channel coefficient for user k and noise $n(j)$ is considered as AWGN sample. In IDMA receiver, the iterative detection scheme is used through the use of elementary signal estimator (ESE) and decoder (DEC). Both ESE and DEC are used to calculate the extrinsic log likelihood ratios (LLRs) in the process of taking decision for final outcome.

$$LLR_{extrinsic}(c_k(j'')) = \log \frac{\Pr(c_k(j'') = +1}{\Pr(c_k(j'') = -1} - LLR_{apriori}(c_k(j'')), \forall k, j'' \tag{11}$$

Basically, IDMA receiver iterates between ESE and DEC in the following steps: (1) ESE evaluates the extrinsic LLR, without considering the coding constraints, and feeds it to DEC as a priori LLR. (2) DEC calculates the extrinsic LLR using local decoders and feeds it to ESE as a priori LLR.

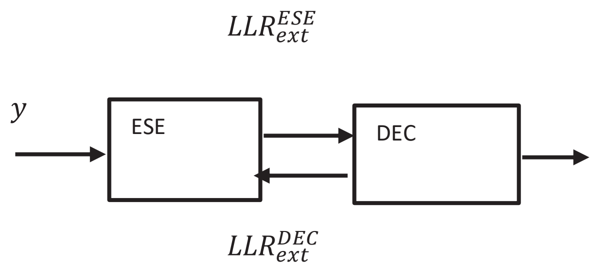

Figure 7. Iteration between ESE and DEC in IDMA receiver.

The operation of decoder (DEC) is standard; however, maximum likelihood (ML) detection can be used at ESE [100]. The complexity of ML-ESE increases with the number of users K. The complexity may further increase for other modulation schemes; for example, the complexity of QPSK modulated transmitted symbols is $O(4^K)$. Further, Gaussian approximation (GA) can be the cost-effective solution for ESE detection. Using the extrinsic information from DEC, the mean and variance of transmitted symbol $x_k(j)$ can be written as

$$\mu_K^x = \mathrm{E}(\mathrm{x_K(j)}) \tag{11}$$

$$v_K^x = \mathrm{Var}(\mathrm{Re}(\mathrm{x_K(j)})) \tag{12}$$

Let us assume that $\mathrm{Re}[x_K(j)] = \sqrt{\frac{p_k}{2}} c_k(j'')$ for the interleaved sequence of length j''. In traditional MRC estimator, the estimated received symbol can be expressed as

$$\hat{x}_k(j) = h_k x_k(j) + \xi_k(j) \tag{13}$$

With the help of GA, the $\xi_k(j)$ can be approximated and extrinsic LLR can be described as

$$LLR_{extrinsic}(c_k(j'')) = \frac{2h_k\sqrt{p_k/2}}{\mathrm{var}(\mathrm{Re}(\xi_k(j))}\mathrm{Re}(\hat{x}_k(j) - E(\xi_k(j))) \tag{14}$$

In the IDMA system model, there are some issues that may have impact on the system performance. They can be as follows:

- Power control: the power control parameter p_k can be optimized for better system performance.
- Interleaver design: in IDMA, the interleaver is crucial for system performance, as the users are distinguished on the basis of chip level interleaver, and interleavers also offer sparsity in IDMA, so that iterative detection may be possible. With random interleaver (RI), IDMA system performs well; however, memory requirement and receiver complexity increased in the case of RI.
- Phase control: the phase of received signal can be controlled to reduce the interference. However, the phase control requires accurate information about channel, i.e., perfect CSIT, which can lead to extra cost on feedback link. Further, the phase typically changes faster than power. On the other hand, to compensate the phase, we need to adjust the phase shift of the channel. In MIMO system, it is usually difficult to adjust the phase shift for all the antennas.

Signal shaping and spatial coupling may be other parameters to take care for the improvement of IDMA system performance. In Fig. (8), the performance of SISO-IDMA is shown with QPSK signaling. It is clear that SPC performs marginally better than EPC at $K = 3$; however, at $K = 6$ and 12, the advantages of SPC are more significant for IDMA. Further, the performances of ML and GA are almost the same at $K = 3$. However, the complexity of GA is much smaller than that of ML. The complexity order of ML $O(4^K)$ becomes almost unbearable at higher values of K such that $K = 6$ and 12. Similarly, the impact of phase control, spatial coupling, and interleaver design can also be evaluated for IDMA system. For detailed analysis, one can refer to Ping, L., Liu, L., Wu, K. and Leung, W.K. (2006) and Aasheesh Shukla et al. (2017).

NOMA IN OTHER DOMAINS

Beyond signal multiplexing in power or code domain, some other NOMA solutions have also been proposed. In this section, NOMA in other domains is discussed.

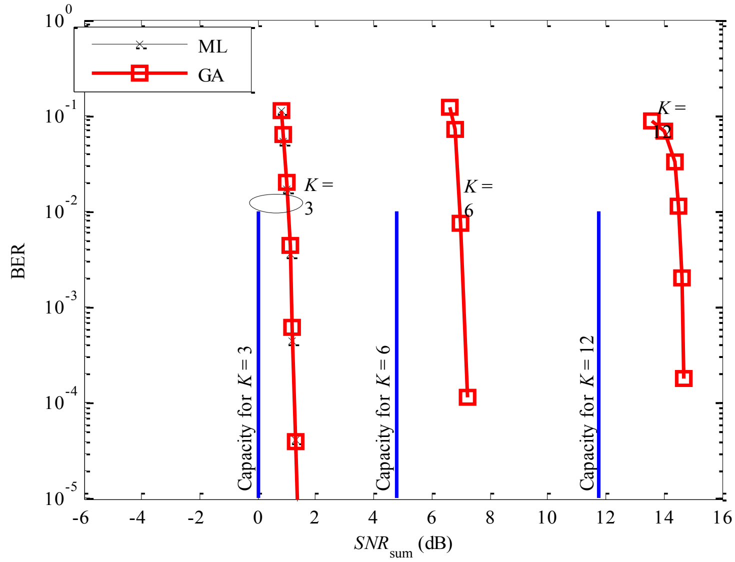

Figure 8. IDMA systems with EPC and SPC over AWGN channels. Rate-1/3 turbo coding followed by rate-1/2 repetition coding is used for each user with QPSK modulation [105].

RSMA

Recently, a new multiple access framework is suggested in Mao, Yijie, Bruno Clerckx, and Victor OK Li (2018), which is named as Rate Splitting Multiple Access (RSMA). Actually, RSMA acts as a bridge between two extremes, i.e., NOMA and SDMA (space division multiple access). In SDMA, linear precoding is used to separate users in the spatial domain, and any residual multiuser interference is fully treated as noise, while in traditional PD-NOMA, the superposition coding with successive interference cancellation is used at transmitter and relies on user grouping to enforce some users to fully decode and cancel interference created by other users. On the other hand, RSMA takes a mid-way between these two extremes; that is, RSMA relies on linearly precoded rate-splitting with SIC to decode part of the interference and treat the remaining part of the interference as noise.

RATE SPLITTING APPROACH

The Rate-Splitting (RS) approach is not a recently proposed concept. The idea of RS predates to Carleial's research on interference channel (IC) and then it appears in the Han-Kobayashi scheme, where it was proved mathematically that decoded part of interference improved the system performance. In Rate-Splitting scheme, the transmitting message is split in two parts: a common part and a private part. The common parts of all users are superimposed to make a super common message, encoded by the code drawn from a code book shared by all users. The private part is encoded by a secure code, known to corresponding user. For K-user system, the K+1 encoded data streams are simultaneously transmitted. At the receiver, the common message is decoded first, and treating all private parts of message as noise and then private message is decoded by desired user through removing the common message via successive interference cancellation (SIC) [8]. It is interesting to note that the multiuser (MU) interference in multi-input single output (MISO) broadcast channel (BC) with imperfect CSIT draws a strong resemblance to the IC. In [xx], it is shown that RS improves the performance of the sum of degrees of freedom (DoF) of MISO-BC channel under imperfect CSIT, where errors decay with increased SNR at a rate of $O(SNR^{-\alpha})$ for some constant$\alpha \in [0,1]$. In this context, it is proved in the literature that RS outperforms the conventional transmission without rate splitting (NoRS) (Mao, Yijie, Bruno Clerckx, and Victor OK Li. 2018).

RSMA SYSTEM MODEL

In this section, the idea of RSMA system with two users is presented. The transmitter block is shown in the figure [9]. w_1 and w_2 are two messages from two users. The message of each user is split into two parts, i.e., $[w_1^{12}\ w_1]$ for the first user and $[w_2^{12}\ w_2]$ for the second user. One part of each message is combined into single message through message combiner. For example, in two-user model, w_1^{12}, w_2^{12} are encoded together to generate s_{12} with the help of common code book.

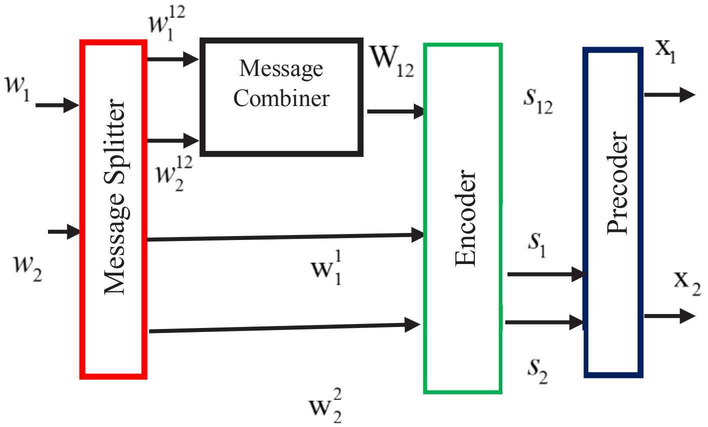

Figure 9. RSMA transmitter block for two users.

Hence, s_{12} is a common message, which is required to be decoded by both users. The rest of the messages of each user, i.e., w_1^1, w_2^2, are encoded by distinct private codes to s_1 and s_2. The overall message stream fed to linear precoder can be written as $[s_{12}\ s_1\ s_2]^T$. The precoder coefficient matrix can be assumed as $p=[p_{12}\ p_1\ p_2]$, and hence, the final transmitted data stream can be given as $x=ps=p_{12}s_{12}+p_1s_1+p_2s_2$.

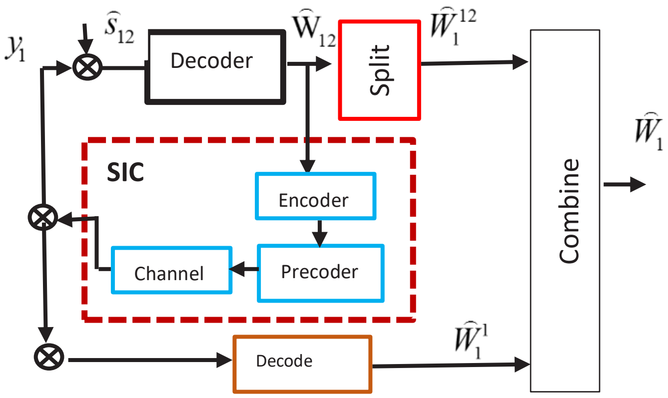

Figure 10. RSMA receiver block for single user.

Fig [10] shows the receiver block of RSMA for one user. User 1 first decodes s_{12}, by treating the interference s_1 and s_2 as noise. The interference is partially decoded at each user. The SINR of the common stream at user k can be given as

$$\gamma_k^{12} = \frac{\left|h_k^H p_{12}\right|^2}{\left|h_k^H p_1\right|^2 + \left|h_k^H p_2\right|^2 + 1} \tag{15}$$

Once s_{12} is fully decoded, the use of y_k is subtracted. The SINR of decoding the private messages s_k at user-k is

$$\gamma_k^{12} = \frac{\left|h_k^H p_k\right|^2}{\left|h_k^H p_j\right|^2 + 1} \tag{16}$$

corresponding to s_{12} and s_k that are $R_k^{12}=\log_2(1+\gamma_k^{12})$ and $R_k=\log_2(1+\gamma_k)$. The weighted sum rate (WSR) for two user rate splitting system can be expressed as

$$\begin{aligned}
&R_{RS_2}(u)=\max\ (u_1 R_{1,tot}+u_2 R_{2,tot}) \\
&\text{s.t. } C_1^{12}+C_2^{12} \le R_{12} \\
&tr(PP^H) \le P_t \\
&R_{k,tot} \ge R_k^{th},\ k \in [1,2] \\
&c \ge 0
\end{aligned} \tag{17}$$

where $c=[C_1^{12},C_2^{12}]$ is the common rate vector, which has to be optimized to maximize the WSR. Table (3) has presented a brief comparison between RSMA, NOMA, and space division multiple access (SDMA).

Table 3. Comparison of RSMA with PD-NOMA and SDMA.

Multiple Access Schemes	**PD-NOMA**	**SDMA**	**RSMA**
Strategy	SC-SIC	MU-LP	All forms of Rate splitting
Design Principle	Full decode of interference	Fully treat interference as Noise	Partially decode of interference and partially treat interference as noise
Decoder Architecture	SIC at Receivers	Treat interference as Noise	SIC at Receivers

User deployment Scenario	User experience aligned channel directions and a large disparity in channel strengths	User channel are semi-orthogonal with similar channel strengths	Any angle between channels and any disparity in channel strengths
Network load	Well suited to overload network	Well suited to underload network	Suited to any network load.

PDMA

In pattern division multiple access (PDMA), the nonorthogonal patterns are allocated to different users to perform multiplexing. At transmitter side, the users are distinguished by sparse signature matrix. For example, seven users can be multiplexed through three resource blocks. The signature matrix can be as follows:

$$\begin{bmatrix} 1 & \sqrt{\frac{3}{2}} & \sqrt{\frac{3}{2}} & 0 & \sqrt{3} & 0 & 0 \\ 1 & \sqrt{\frac{3}{2}} & 0 & \sqrt{\frac{3}{2}} & 0 & \sqrt{3} & 0 \\ 1 & 0 & \sqrt{\frac{3}{2}} & \sqrt{\frac{3}{2}} & 0 & 0 & \sqrt{3} \end{bmatrix} \tag{18}$$

With the use of signature matrix, the system capacity can be improved in overloaded network scenario. At the PDMA receiver, MPA detection strategy can be adopted for detection. For power or space domain, MPA-SIC detection scheme can be used in PDMA receiver. A turbo structure can also be combined with receiver to further enhance the performance of PDMA (Chen S, Sun S, Kang S, Ren B.2019).

BOMA

In this technique, the signal of the user with good CSI is attached to the user with poor CSI. Hence, the capacity of the system is increased significantly. This multiple access scheme can be abbreviated as 'block sparse-constellation based orthogonal multiple access' (BOMA). In order to achieve the same BER performance as a user with good CSI, the coarse constellation is applied by the user with poor CSI with the large minimum distance. Hence, the information of the user with good CSI can be tiled in the constellation of the user with poor CSI. The structure of the BOMA is simple and convenient to adjust with the existing 4G systems. With the minor changes in software, the BOMA can be easily adapted in massive MIMO systems. The performance of BOMA remains good, without the use of power allocation and SIC in receiver. Hence, the receiver in BOMA is less complex and easily compatible with existing systems (Deng, L. et al., 2018).

LPMA

In lattice partition multiple access (LPMA), the power domain and code domain are combined to enhance the system performance. Different codes are used to users with different CSI. For users with the poor CSI, the allocated codes have large minimum distance that can improve the detection performance. The users with better CSI can have codes with smaller minimum distance without degrading the system performance. The receiver can also employ SCI for the better system performance. Besides the code domain multiplexing, the LPMA can also utilize the power domain multiplexing to enhance the performance of the user with poor CSI. With the aid of two degrees of freedom, the design of LPMA becomes more effective than power domain or code domain NOMA alone (Claussen, H. et al., 2016).

COMPARATIVE ANALYSIS, CHALLENGES, AND FUTURE WORK

In the above, many NOMA schemes have been discussed. In this section, the comparative analysis of all and future challenges are presented.

Table 4. Comparison of Multiple Access Schemes.

Schemes	Characteristics	Receivers Algorithm	Merits	De-merits
Power-domain NOMA	Multiplexing in power domain	• SIC	• High spectral efficiency • Compatible to other schemes	• Need user pairing • Error propagation in SIC
LDS-CDMA	Low density spreading sequence used in CDMA	• MPA	• No need of CSI • MPA detector is used	• Redundancy from coding
LDS-OFDM	Low density spreading sequence used in OFDM	• MPA	• No need of CSI • MPA detector is used • Suitable for wideband application than LDS-CDMA	• Redundancy from coding
SCMA	Sparse code Multiple Access	• MPA	• No need of CSI • MPA detector is used • More diversity than LDS-CDMA	• Redundancy from coding • Code book design is difficult
IDMA	Interleaver is used to differentiate users	• ESE-PIC	• No need of CSI • Iterative detection between ESE and DEC	• Storage requirement at receiver • Not good in delay-sensitive applications

RSMA	Rate splitting is utilized for multiple access	• SIC	• Low complexity receiver • Rate enhancement over PD-NOMA • No need of CSI	• Higher encoding complexity
PDMA	Sparse pattern matrix used for multiplexing in power, code or spatial domain	• MPA • SIC-MPA • SIC	• Low complexity receiver • High diversity • Optimal MPA detector	• Designing of pattern code book is complex • Redundancy from coding
BOMA	User with good CSI can be tiled in the constellation of the user with poor CSI	• MSED	• Low complexity receiver • Simple system architecture • Compatible to existing system	• User pairing is required
LPMA	Laiitce code-based multiplexing	• Modulo lattice operation with SIC (MLO-SIC)	• User grouping is not required	• Efficient channel coding is needed

In Table (4), an attempt has been made to compare all popular NOMA solutions on the basis of certain parameters. Their merits and limitations are also mentioned in the table. The PD-NOMA has a simple structure and is compatible to all existing technologies, such as massive MIMO and cooperative networks. However, complexity arises due to the need of user pairing or user clustering. Further, code domain NOMA, such as IDMA and SCMA, can have spreading gain without the need of CSI.

IDMA utilizes the iterative detection with ESE, and SCMA uses low complex near optimal MPA detector, which has better performance than SIC detectors. However, coding redundancy is the main problem that leads to poor spectral efficiency (SE). Other NOMA schemes such as RSMA offer performance improvement due to the concept of rate splitting. In RSMA, part of the interference is decoded, and the remaining part of the interference is treated as noise. The encoder complexity is higher as the rate splitting is a crucial phenomenon in RSMA. BOMA has simple architecture and is flexible in adapting with the current LTE system although user paring is the required phenomenon in BOMA, which reduces the flexibility of the system. LPMA utilizes the concept of lattice code-based multiplexing, which reduces the cost of user grouping. However, specific channel coding is required.

Table (4) illustrates the comparative analysis of different MA schemes, which states the advantages and disadvantages and can help find an optimum multiple access scheme for suitable applications. Actually, it is a tradeoff among different parameters such as implementation complexity, performance, and detection scheme to find an efficient multiple access scheme for a dedicated wireless network.

Several NOMA solutions have been discussed so far, mainly focused on code domain NOMA and some other MA schemes such as RSMA. NOMA schemes have already been considered as a promising candidate for 5G networks and beyond communication. However, there may be certain key challenges in NOMA design. Hence, some main issues are highlighted below in the discussion.

- In IDMA (CD-NOMA), an efficient interleaver design is the key challenge. Random interleaver has good BER performance; however, the storage requirement and detection complexity are so high. So, an interleaver design that has BER performance near to random interleaver with less storage requirement can be a good motivation for further research work in CD-NOMA solutions. Apart from this, in SCMA and PDMA, MPA-SIC detection scheme is used, where user clustering/grouping can affect the performance of the system. In case of asynchronous users, a multibranch technique is suggested for better performance of the system. Furthermore, attention can be paid to research for a good scheme to get better user clustering.
- The joint processing of different types of NOMA schemes can be an interesting direction to be explored for an efficient multiple access for 5G and beyond networks. In [], the framework of new multiple access technique is suggested in which joint processing of SCMA and power domain NOMA has been proposed. Similarly, the LDS-CDMA can be combined with OFDM as the outcome of sparse coding matrix in LDS-CDMA is mapped to orthogonal subcarriers.
- Almost all NOMA solutions have assumed the perfect CSI in the transmission. However, this is unrealistic, as the perfect knowledge of channel is not possible in the practical communication link design. So, channel estimation errors are so common in NOMA schemes. Some optimization schemes have been suggested to tackle the channel estimation error. Nevertheless, the increase in number of users in 5G and future communication networks will cause more interuser-interference; henceforth, more channel estimation error will occur in the NOMA system; therefore, more robust and efficient optimization algorithms are required to mitigate the channel estimation error.
- In NOMA receiver, power allocation is crucial as, by doing accurate power allocation, the receiver can have better capacity to cancel the interference. Hence, the search of a dynamic power allocation can be a new research topic to make NOMA useful for various applications.
- It is desirable to use the NOMA with other recently proposed schemes, such as massive multi-input and multioutput (MIMO) and millimeter wave communication. An effective beamforming scheme can also be added to massive MIMO aided PD-NOMA system. Further, millimeter wave communication and Tera-Hz band can be good options to decrease the scarcity of available bandwidth. However, still, these bands have poor propagation characteristic and, hence, good research opportunities with NOMA.
- Some other challenges and opportunities associated with NOMA can be addressed, such as signal design for NOMA, cooperative communication, base station cooperation, and PAPR reduction in multicarrier NOMA system.

CONCLUSIONS

In this article, the comprehensive survey of different available multiple access scheme is presented, which are recent and can be used for 5G wireless networks. Most of the literature focused on power domain NOMA scheme; however, in this article, the code domain NOMA schemes are prominently presented. The basic concept and operating principle of all discussed MA schemes have also been given with their merits and demerits. The comparative analysis of all advanced MA schemes is also given to find the optimum MA scheme for the required application. The key challenges and opportunities in NOMA schemes are highlighted at the end of the paper to address the researchers for the future research in the NOMA schemes. Undoubtedly, NOMA will play an important role in 5G and future communication networks by utilizing massive connectivity and improving spectral efficiency.

REFERENCES

S. M. R. Islam, M. Zeng, and O. A. Dobre, (2017) NOMA in 5G systems: exciting possibilities for enhancing spectral efficiency. IEEE 5G Tech Focus, vol. 1, no. 2, pp. 1–6.

W. Shin et al., (2017). Non-orthogonal multiple access in multi-cell networks: Theory, performance, and practical challenges. IEEE Commun. Mag., vol. 55, no. 10, pp. 176–183.

L. Dai et al., (2015). Non-orthogonal multiple access for 5G: Solutions, challenges, opportunities, and future research trends. IEEE Commun. Mag., vol. 53, no. 9, pp. 74–81.

Z. Ding et al., (2017) A survey on non-orthogonal multiple access for 5G networks: Research challenges and future trends. IEEE J. Sel. Areas Commun., vol. 35, no. 10, pp. 2181–2195.

M. S. Ali, E. Hossain, and D. I. Kim, (2016). Non-orthogonal multiple access (NOMA) for downlink multiuser MIMO systems: User clustering, beam forming, and power allocation. IEEE Access, vol. 5, pp. 565–577.

Z. Wei, J. Yuan, D. W. K. Ng, M. Elkashlan, and Z. Ding, (2016) A survey of downlink non-orthogonal multiple access for 5G wireless communication networks. ZTE Commun., vol. 14, no. 4, pp. 17–23.

Y. Liu, G. Pan, H. Zhang, and M. Song, (2016) On the capacity comparison between MIMO-NOMA and MIMO-OMA, IEEE Access, vol. 4, pp. 2123–2129.

Xu, C., Hu, Y., Liang, C., Ma, J. and Ping, L., (2017) Massive MIMO, non-orthogonal multiple access and interleave division multiple access. IEEE Access, 5, pp.14728-14748.

S. M. R. Islam, N. Avazov, O. A. Dobre, and K.-S. Kwak, (2017) Power domain non-orthogonal multiple access (NOMA) in 5G systems: Potentials and challenges. IEEE Commun. Surveys Tuts. vol. 19, no. 2, pp. 721–742.

Kader, Md Fazlul. (2020) A power-domain NOMA based overlay spectrum sharing scheme." Future Generation Computer Systems 105 pp 222-229.

Z. Ding, Z. Yang, P. Fan, and H. V. Poor, (2014). On the performance of non-orthogonal multiple access in 5G systems with randomly deployed users. IEEE Signal Process. Lett. vol. 21, no. 12, pp. 1501–1505.

Iswarya, N., & Jayashree, L. S. (2021). A Survey on Successive Interference Cancellation Schemes in Non-Orthogonal Multiple Access for Future Radio Access. Wireless Personal Communications, 1-22.

Shukla, Aasheesh. (2021). Comparative analysis of various code domain NOMA schemes for future communication networks. Materials Today: Proceedings.

M. Al-Imari, M. A. Imran, R. Tafazolli, and D. Chen, (2012) Performance evaluation of low density spreading multiple access. IEEE Wireless Commun. Mobile Comput. Conf. (IEEE IWCMC), Limassol, Cyprus.

Awasthi, V., & Av, B. (2021). Performance Analysis of NOMA-Based Underlay Cognitive Radio Networks with Partial Relay Selection. IEEE Transactions on Vehicular Technology.

Al-Imari, Mohammed, and Muhammad Ali Imran. (2019) Low Density Spreading Multiple Access. In Multiple Access Techniques for 5G Wireless Networks and Beyond, pp. 493-514. Springer, Cham.

Chen, Yen-Ming, and Jian-Wei Chen. (2020) On the Design of Near-optimal Sparse Code Multiple Access Codebooks. IEEE Transactions on Communications, Feb.

Sharma, Sanjeev, Kuntal Deka, Vimal Bhatia, and Anubha Gupta. (2020) Joint power-domain and SCMA-based NOMA system for downlink in 5G and beyond. IEEE Communications Letters 23, no. 6, pp 971-974.

Jibreel, Nareeman, Salma Elkawafi, Abdelhamid Younis, and Raed Mesleh. (2020) Performance analysis of sparse code multiple access with variant MIMO techniques. Physical Communication 39, 101023.

S. Zhang, B. Xiao, K. Xiao, Z. Chen, and B. Xia, (2015) Design and analysis of irregular sparse code multiple access. IEEE Int. Conf. Wireless Commun. Signal Process. (IEEE WCSP).

A. Bayesteh, E. Yi, H. Nikopour, and H. Baligh, (2014) Blind detection of SCMA for uplink grant-free multiple-access. IEEE Wireless Commun. Syst. (IEEE ISWCS), Barcelona, Spain.

L. Lu et al., (2015) Prototype for 5G new air interface technology SCMA and performance evaluation. China Commun., vol. 12, no. 1, pp. 38–48.

Ping, L., Liu, L., Wu, K. and Leung, W.K., (2006) Interleave division multiple-access. IEEE transactions on wireless communications, 5(4), pp.938-947, April 2006

Aasheesh Shukla, and Vinay Kumar Deolia. (2017) Performance analysis of modified tent map interleaver in IDMA systems. Journal of Electrical Engineering 68, no. 4 pp 318-321.

Chen, X., Liu, C., Nian, L., Cheng, M., Fu, S., Tang, M., & Deng, L. (2018). BOMA and OFDM/OQAM modulation for a radio-over-fiber system with enhanced spectral efficiency. Optics letters, 43(20), 4859-4862.

Mao, Yijie, Bruno Clerckx, and Victor OK Li. (2018) Rate-splitting multiple access for downlink communication systems: bridging, generalizing, and outperforming SDMA and NOMA. EURASIP Journal on Wireless Communications and Networking, no. 1, pp 133.

Fang, D., Huang, Y. C., Ding, Z., Geraci, G., Shieh, S. L., & Claussen, H. (2016). Lattice partition multiple access: A new method of downlink non-orthogonal multiuser transmissions. In 2016 IEEE global communications conference, 1-6

Chen S, Sun S, Kang S, Ren B. (2019) Pattern Division Multiple Access (PDMA). In Multiple Access Techniques for 5G Wireless Networks and Beyond, pp. 451-492.

Almutairi, Ali F., Mishal Al-Gharabally, and Ayed A. Salman (2021). Particle swarm optimization application for multiple attribute decision making in vertical handover in heterogenous wireless networks." Journal of Engineering Research 9, no. 1 pp 176-187.