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Comparative analysis of various code domain NOMA schemes for future communication networks

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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. Based on the recently proposed NOMA scheme, one MA domain can be based on signature code, which is named as code domain NOMA. This scheme can support large number of user's transmission in same time/frequency resource block by assigning different signature codes to different users. An interesting feature is associated with code-domain NOMA is that it can perform better in power balanced scenarios, when all the signature sequences are unique. This paper presents the comparative analysis of various code domain NOMA Schemes. Further, the opportunities and challenges could be notified in code domain- NOMA schemes and the optimum MA technique can be point out for 5G and beyond communication network.

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1. 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. To get the better throughput and to improve spectrum utilization, many multiple access (MA) schemes have been proposed in time, frequency and space domain. Broadly, MA schemes can be classified in to two categories, namely orthogonal multiple access (OMA) and non-orthogonal multiple access (NOMA) scheme [3,4]. 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 [1,2,7].

In TDMA, many users utilized the whole spectrum in certain assigned time slots, whereas in FDMA, users could communicate through assigned frequency channels. Under-utilization of frequency spectrum in FDMA and synchronization in TDMA were major concerns with these MA schemes [3–6]. 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 [6]. 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 [8–10]. NOMA does not required orthogonality among resources, it simply offers multiplexing within one 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 [10–14] schemes can be broadly studied in two categories namely power domain NOMA (PD-NOMA) and code domain NOMA (CD-NOMA). In this paper, the focus is mainly on code domain NOMA schemes. The rest of this article is organized as follows. In Section 2, popular MA candidates of code domain NOMA are introduced. In Section 3, comparative analysis of different MA schemes have discussed and finally, Section 4 concludes this article.

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2. Code domain NOMA schemes

2.1. LDS-CDMA

In this scheme, the signature sequences are provided to each user and are fully transparent to receiver. Fig. 1 shows the LDS structure to generate the spreading sequences. Assume the length of spreading sequence (chip length) is$N$. In conventional CDMA all the Nchips are non-zero and optimized on the basis of auto/cross correlation. Whereas in the proposed LDS structure the Nchips are arranged in such a way that each user spread its data over a small number of chips d_v

Further, after doing zero padding the chips are interleaved in a way, such that resultant spreading sequence matrix become 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 detection the LDS spreading sequence. The performance evaluation of LDS based CDMA communication system is presented in [10] and simulation results shows the obvious improvement in the performance of LDS- CDMA over conventional CDMA

2.2. LDS-OFDM

The characteristics of LDS-OFDM system is very similar to the LDS-CDMA system, except that the spreading sequences can be mapped in to the multiple sub carriers. 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 [11].

2.3. SCMA

In [12,13], sparse code multiple access has been proposed, which can be considered as modified and improved version of LDS-CDMA. As shown in Fig. 2, in SCMA, the bit to QAM mapper and spreading is combined and incoming message bits are directly mapped to SCMA codebook set.

SCMA is having certain characteristics, which can be listed as below;

- 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.

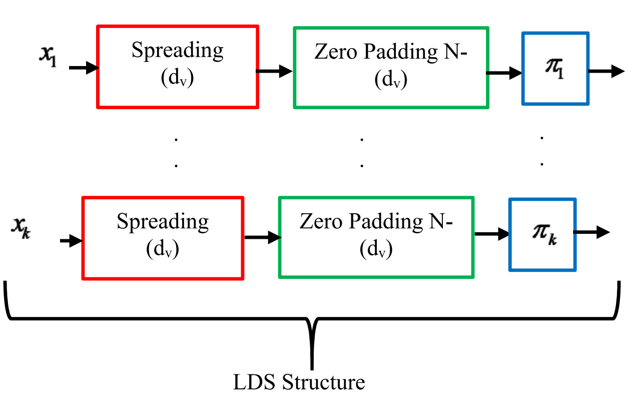

Fig. 1. LDS structure for signature sequence generation.

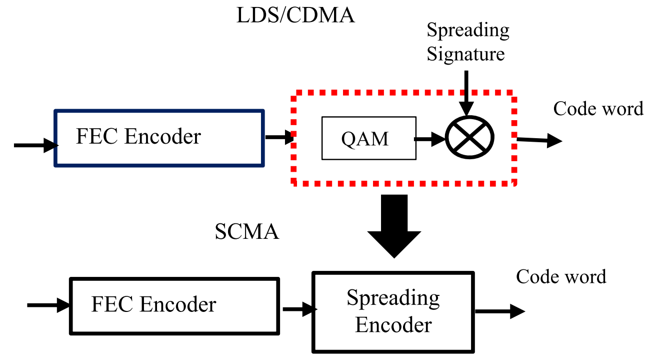

Fig. 2. Merging of QAM and spreading to generate the SCMA code-word.

2.4. 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 s special case of direct sequence- code division multiple access (DS-CDMA). 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 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 as shown in Fig. 3 [14].

2.4.1. IDMA system model

For simplicity, the SISO-IDMA system can be considered. Let$\{d_k\}$ is the data and $\mathbf{c_k} = \{c_k(j)\}$is 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 [14];

$$x_k(j) = \sqrt{p_k} c_k(j^{''}) \tag{1}$$

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;

$$y(j) = \sum_{k=1}^{K} h_k x_k + n(j) \tag{2}$$

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.

$$LLR_{extrinsic}(c_k(j'')) = \log \frac{\Pr(c_k(j'') = +1}{\Pr(c_k(j'') = -1} - LLR_{apriori}(c_k(j'')), \forall k, j'' \tag{3}$$

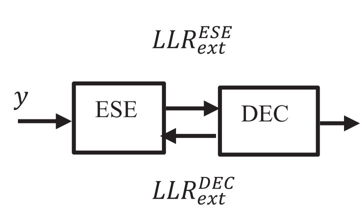

Fig. 3. Iteration between ESE and DEC in IDMA receiver.

Table 2
Comparison of Multiple Access Schemes.

Schemes	Characteristics	Receivers Algorithm	Merits	De-merits
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

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

The operation of decoder (DEC) is standard, however maximum likelihood (ML) detection can be used at ESE [14]. The complexity of ML-ESE increases as 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. In [14] the MRC estimator with GA is suggested, which is as follows. Using the extrinsic information from DEC, the mean and variance of transmitted symbol $x_k(j)$ can be written as;

$$\mu_K^x = \mathrm{E}(\mathrm{x_K(j)}) \tag{4}$$

$$\upsilon_K^x = \mathrm{Var}(\mathrm{Re}(\mathrm{x_K(j)})) \tag{5}$$

3. Comparative analysis

In this section, the comparative analysis among all code domain NOMA Schemes have been presented. In Table 1 and Table 2 an attempt has been made to compare all popular code domain-NOMA solutions on the basis of certain parameters. Their merits and limitation also mentioned in the table. The code-domain NOMA, such as IDMA, 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 which lead to poor spectral efficiency (SE).

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

4. Conclusions

In this article, various code domain NOMA schemes are prominently presented. The basic concept and operating principle of all CD-NOMA schemes have also given with their merits and demerits. The comparative analysis of all advanced MA schemes is also given to find the optimum MA scheme for a dedicated application. Undoubltly, NOMA will play an important role in 5G and future communication networks by utilizing massive connectivity and improved spectral efficiency.

CRediT authorship contribution statement

Aasheesh Shukla: Conceptualization, Methodology, Writing - review & editing, Software, Validation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] Z. Yang, Z. Ding, P. Fan, G.K. Karagiannidis, On the performance of non-orthogonal multiple access systems with partial channel information, IEEE Trans. Commun. 64 (2) (2016) 654–667.
[2] Q.i. Sun, S. Han, C.-L. I, Z. Pan, On the ergodic capacity of MIMO NOMA systems, IEEE Wireless Commun. Lett. Apr. 4 (4) (2015) 405–408.
[3] S. Timotheou, I. Krikidis, Fairness for non-orthogonal multiple access in 5G systems, IEEE Signal Process. Lett. 22 (10) (Oct. 2015) 1647–1651.
[4] K. Yakou, K. Higuchi, ''Downlink NOMA with SIC using unified user grouping for non-orthogonal user multiplexing and decoding order,'' in Proc. IEEE Int. Symp. Intell. Signal Process. Commun. Syst. (IEEE ISPACS), Nov. 2015, pp. 508–513.
[5] J. Choi, On the power allocation for a practical multiuser superposition scheme in NOMA systems, IEEE Commun. Lett. 20 (3) (2016) 438–441.
[6] R. Hoshyar, F.P. Wathan, R. Tafazolli, Novel low-density signature for synchronous CDMA systems over AWGN channel, IEEE Trans. Signal Processing 56 (4) (2008) 1616–1626.
[7] R. Razavi, R. Hoshyar, M.A. Imran, Y. Wang, Information theoretic analysis of LDS scheme, IEEE Commun. Lett. 15 (8) (2011) 798–800.
[8] R. Hoshyar, R. Razavi, and M. Al-Imari, ''LDS-OFDM an efficient multiple access technique,'' in Proc. IEEE Veh. Technol. Conf. (IEEE VTC Spring), Taipei, Taiwan, May 2010, pp. 1–5.
[9] Hoshyar, Reza, Razieh Razavi, and Mohammad Al-Imari. ''LDS-OFDM an efficient multiple access technique.'' In 2010 IEEE 71st Vehicular Technology Conference, pp. 1-5. May, 2010.
[10] L. Meylani, I. Hidayat, A. Kurniawan, M. Sigit Arifianto, Power Allocation for Group LDS-OFDM in Underlay Cognitive Radio, in: In 2019 11th International Conference on Information Technology and Electrical Engineering (ICITEE), Oct 2019, pp. 1–5.
[11] M. Al-Imari, M. A. Imran, R. Tafazolli, and D. Chen, ''Performance evaluation of low density spreading multiple access,'' in Proc. IEEE Wireless Commun. Mobile Comput. Conf. (IEEE IWCMC), Limassol, Cyprus, Aug. 2012, pp. 383–388.

[12] M. Al-Imari, M. A. Imran, and R. Tafazolli, "Low density spreading for next generation multicarrier cellular systems," in Proc. IEEE Future Commun. Netw. (IEEE ICFCN), Baghdad, Iraq, Apr. 2012, pp. 52–57.

[13] M. Taherzadeh, H. Nikopour, A. Bayesteh, and H. Baligh, "SCMA codebook design," in Proc. IEEE Veh. Technol. Conf. (IEEE VTC Fall), Vancouver, BC, Canada, Sep. 2014, pp. 1–5. [96] L. Yu, X. Lei, P. Fan, and D. Chen, "An optimized design of SCMA codebook based on star-QAM signaling constellations," in Proc. IEEE Int. Conf. Wireless Commun. Signal Process. (IEEE WCSP), Nanjing, China, Oct. 2015, pp. 1–5.

[14] A. Shukla, S. Kumar, V. Goyal, V.K. Deolia, Performance Boosting in IDMA System Using Helical Interleaver and Gold Codes, in: In 2012 Fourth International Conference on Computational Intelligence and Communication Networks, Nov 2012, pp. 387–390.