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A Systematic Review on NOMA Variants for 5G and Beyond 5G Networks

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ABSTRACT Over the last few years, interference has been a major hurdle for successfully implementing various end-user applications in the fifth-generation (5G) of wireless networks. During this era, several communication protocols and standards have been developed and used by the community. However, interference persists, keeping given quality of service (QoS) provision to end-users for different 5G applications. To mitigate the issues mentioned above, in this paper, we present an in-depth survey of state-of-the-art non-orthogonal multiple access (NOMA) variants having power and code domains as the backbone for interference mitigation, resource allocations, and QoS management in the 5G environment. These are future smart communication and supported by device-to-device (D2D), cooperative communication (CC), multiple-input and multiple-output (MIMO), and heterogeneous networks (HetNets). From the existing literature, it has been observed that NOMA can resolve most of the issues in the existing proposals to provide contention-based grant-free transmissions between different devices. The key differences between the orthogonal multiple access (OMA) and NOMA in 5G are also discussed in detail. Moreover, several open issues and research challenges of NOMA-based applications are analyzed. Finally, a comparative analysis of different existing proposals is also discussed to provide deep insights to the readers.

INDEX TERMS NOMA, OMA, Uplink, Downlink, Device-to-Device, Machine-to-Machine.

I. INTRODUCTION

The exponential growth and usage of smart devices such as smartphones, wearable gadgets, sensors, actuators in the Internet-based applications such as ultra high definition (HD) video transmission, live streaming, augmented reality, virtual reality, real-time video calling, live conferences, and social network services, generates a huge amount of data traffic. It creates an overburden on the long term evolution (LTE)/ long term evolution- advanced (LTE-A) spectrum due to which spectral efficiency (SE) of the underlying backbone network infrastructure degrades. Cisco predicted that by 2023 there would be 14.7 billion devices connect to the Internet of Things (IoT) [1]. Also, from compound annual growth report [1], 2018 forecasts that more than 78 billion connected devices will utilize the cellular network services by the end of the year 2023 as shown in Fig. 1. To overcome this problem, various research organizations are keen to use the 5G wireless network that is expected to be fully commercialized by 2023.

To provide a better quality of service (QoS) and quality of experience (QoE) to the end-users, various organizations and countries are putting a lot of efforts into different collaborative projects such as-IMT-2020 (3GPP), 5GPPP/METIS (European Union (EU)), 5G Forums (Korea), and ARIB (Japan). In 2015, International Telecommunication Union-

TABLE 1: Nomenclature

Acronym	Explanation	Acronym	Explanation	Acronym	Explanation
5G	Fifth Generation	CUs	Cellular Users	HAP	Hybrid Access Point
5GPPP	Fifth Generation Public Partnership Project	D2D	Device-to-Device	HARQ	Hybrid Automatic Repeat Request
AF	Amplify and Forward	DA-NOMA	Delay Aware NOMA	HB	Hybrid Beamforming
AI	Artificial Intelligence	DBIRA	Dual based Iterative Resource Allocation	HD	High Definition
ANFDR	Artificial Noise Full Duplex Relay	DBS	Distributed Base Station	HD	Half Duplex
ANHDR	Artificial Noise Half Duplex Relay	DC-NOMA	D2D aided Cooperative NOMA	HDAF	Hybrid Decode Amplify and Forward
ANOMA	Asynchronous NOMA	DCO	Direct Current Optical	HetNets	Heterogeneous Networks
AS	Antenna Selection	DDF	Dynamic Decode and Forward	H-NOMA	Hybrid NOMA
BA	Buffer Aided	DF	Decode and Forward	IA	Interference Alignment
BC	Backscatter Cooperation	DH	Dynamic Hybrid	IBPA	Inversion-based Pairing Algorithm
BD/BDMA	Beam Division/ Beam Division Multiple Access	DL	Deep Learning	ICA	Interference Channel Alignment
BER	Bit Error Rate	D-NOMA	Dynamic NOMA	IDMA	Interleave Division Multiple Access
BF	Beamforming	DPA	Dynamic Power Allocation	IGMA	Interleave Grid Multiple Access
BLER	Block Error Rate	DPS	Dynamic Power Scheduling	IMT	International Mobile Telecommunication
BN	Backscatter Nodes	D-R	Destination Relay	IoT	Internet of Things
BNBF	Best Near Best Far	DRL	Deep Reinforcement Learning	ITU-R	International Telecommunication Union-Radio
BOMA	Beam-orthogonal Multiple Access	DRS	Dynamic Relay selection	IR	Incremental Relaying
BRS	Best Relay Selection	DSA	Dynamic Spectrum Allocation	JA-STSK	Joint-Alphabet Space Time Shift Keying
BS	Base Station	EAB	Enhanced Access Bearing	JP	Joint Processing
CAGR	Compound Annual Growth Rate	EC	Edge Caching	JT	Joint Transmission
CAP	Carrier less Amplitude Phase	EE	Energy Efficiency	LCRS	Low Code Rate Spreading
CCU	Cell Center User	EEPA	Energy Efficient Power Allocation	LDPC	Low Density Parity Check
CDF	Cumulative Density Function	EMC	Electromagnetic Capability	LDS	Low Density Spreading
CDMA	Code Division Multiple Access	EPA	Expectation Propagation Algorithm	LDS-CDMA	Low Density Spreading-CDMA
CD-NOMA	Code Division Non-Orthogonal Multiple Access	ESE	Elementary Signal Estimator	LDS-OFDMA	Low Density Spreading-OFDMA
CDRT	Coordinated Direct and Relay Transmission	ETT	Equal Transmission Time	LDS-SVE	Low Density Spreading-Signature Vector Extension
CEU	Cell Edge User	FD	Full Duplex	LPMA	Lattice Pattern Multiple Access
CFO	Carrier Frequency Offset	FDMA	Frequency Division Multiple Access	LSSA	Low Code Rate and signature based Shared Access
CFR	Coordinated Full Duplex Relaying	FFR	Fractional Frequency Reuse	LTE-A	Long Term Evolution Advanced
CMR	Cooperative Multi-relay	FL	Federated Learning	M2M	Machine-to-Machine
CNAR	Collaborative NOMA Assisted Relaying	F-NOMA	Fixed NOMA	MBMS	Multimedia Broadcast/Multicast Service
C-NOMA	Cooperative NOMA	FPA	Fixed Power Allocation	MCIK	Multi-carrier shift Keying
CO	Coordinated	FRAB	Finite Resolution Analog Beamforming	MDMA	Multipath Division Multiple Access
CoMP	Coordinated Multipoint Transmission	F-SUS	Fairness Oriented Secondary User Scheduling	MEC	Mobile Edge Computing
CQI	Channel Queue Indicator	FTN-FrCT	Faster-Than-Nyquist Fractional Cosine Transform	METIS	Mobile and Wireless Communication Enablers for the Twenty Information Society
CR	Cognitive Radio	GF	Grant Free	MGF	Moment Generating Function
CRN	Cognitive Radio Network	GFDM	Generalised Frequency Division Multiplexing	MIMO	Multiple Input Muliplt Output
CRS	Cooperative Relay Selection	GOCA	Group-Orthogonal Coded Access	mMIMO	massive Multiple Input Multiple Output
CS	Compressed Sensing	GP	Gradient Projection	MMSE	Maximum Mean Square Error
CS/CB	Coordinated Scheduling/Beamforming	GRPA	Gain ratio Power Allocation	mMTC	massive Machine Type Communication
CSC	Coordinated Superposition Coding	GSM	Global System For Mobile	mmWave	Millimeter Wave
CSI	Channel State Information	GSSK	Generalised Space Shift Keying	MPA	Message Passing Algorithm
CSS	Cooperative Spectrum Sensing	H2H	Human-to-Human	MRC	Maximal Ratio Combining

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TABLE 2: Nomenclature

Acronym	Explanation	Acronym	Explanation	Acronym	Explanation
N-NOMA	Network NOMA	PSMA	Power Domain Sparse Code Multiple Access	SWIPT	Simultaneous Wireless Information Power Transfer
NOCA	Non-orthogonal Coded Access	PSO	Particle Swarm Optimization	TC-NOMA	Turbo Code NOMA
NOMA	Non-Orthogonal Multiple Access	PU	Primary Users	TDMA	Time Division Multiple Access
OMA	Orthogonal Multiple Access	QAM	Quadrature Amplitude Modulation	TR	Time Reversal
OMP	Orthogonal Multiple Pursuit	QoS	Quality of Service	TTMMA	Trellis Tone Modulation Multiple Access
OP	Outage Probability	QPSK	Quadrature Phase Shift Keying	TW	Two Way
PAPR	Power-to-Average Power Ratio	RA	Random Access	TWR	Two Way Relay
PAR	Power Allocation Ratio	RA	Resource Allocation	UAV	Unmanned Aerial Vehicle
PBPA	Projection based Pairing Algorithm	RA-CEMA	Rate Adaptive Constellation Expansion	UWB	Ultra Wide Bandwidth
PC-NOMA	Polar Code NOMA	SBF	Secrecy Beamforming	VNI	Visual Networking Index
PDF	Probability Density Function	SE	Spectral Efficiency	VP	Virtual Pairing
PDMA	Pattern Division Multiple Access	SOMA	Semi-Orthogonal Multiple Access	WPCN	Wireless Powered Communication Network
PD-NOMA	Power Domain NOMA	S-R	Source Relay	WSMA	Welch bound Spreading Multiple Access
PEP	Pairwise Error Probability	SSK	Space Shift Keying	WSN	Wireless Sensor Network
PFDM	PU First Decoding Method	SSMA	Short Sequence Spreading Multiple Access	ZF	Zero Forcing
PLC	Power Line Communication	SU	Secondary User	ZFBF	Zero-Force Beamforming

Radiocommunication (ITU-R) officially named the 5G wireless network as IMT-2020 and proposed initial paradigm, key features, and applications [2]–[4]. The first phase of 5G standard was studied under 3GPP Release (Rel.) 15 having key features as follows [3]; i) connection density is 10,00000/km^2, ii) bandwidth is 1 to 2GHz, iii) data rate is 20/10Gbps (downlink/uplink), iv) latency less than 1ms, v) spectral efficiency of 120 bps/Hz, vi) throughput of 10Gbps, vii) usage of Massive MIMO that enhances coverage and capacity, viii) process and transmit information in real-time with high speed up to 1-2Gbps, ix) frequency band (mmWave) 30 to 300 GHz, x) mobility of 500Kmph, xi) area traffic capacity 10 $Mbits/s/m^2$, and xii) energy efficiency (EE) 50 to 100 times more in comparison to IMT-A.

ITU-R classifies the applications of 5G networks into three broad categories; i) enhanced mobile broadband (eMBB) connection, ii) massive machine-type communications (mMTC), and iii) ultra-reliable low latency communication (URLLC). To meet the criteria in 5G, the integration of the following technologies, software-defined network (SDN), coordinated multipoint (CoMP), cooperative communication, device-to-device (D2D) communication, visible light communication (VLC), machine-to-machine (M2M) communication, cognitive radio network (CRN), small cells, massive multiple-input multiple-output (mMIMO), millimeter wave (mmWave), and vehicle-to-everything (V2X) is greatly needed [3]–[5].

The aforementioned integration of different technologies can serve many users from the same resource block (RB) to enhance SE. However, managing asynchronous data generated by machines to provide massive connectivity and diversified QoS to end-users is challenging. To overcome this issue, efficient multiple access (MA) techniques such as orthogonal multiple access (OMA) and non-orthogonal multiple access (NOMA) are required. Among these two techniques, OMA cannot solve the aforementioned problem due to the following reasons; i) bandwidth wastage due to the allocation of one orthogonal resource block to each user, and ii) high signaling overhead and low access efficiency. Hence, NOMA techniques are exploited under the standard 3GPP NR Rel.-14 (downlink) and 3GPP NR Rel.-15 (uplink), especially to handle the aforementioned problems in the 5G environment.

In the NOMA protocol, one RB serves more than one user, and one user can use more than one RB to improve their data rate. The users' signal is multiplexed at the transmitter side using superposition coding (SC) and demultiplexed at the recipient site using the successive interference cancellation (SIC) technique. The usage of SC enhances the sum rate, user fairness, and scheduling flexibility. On the other hand, the inter-user interference created by SC multiplexing can be eliminated by SIC. NOMA is broadly classified into power-domain NOMA (PD-NOMA) and code-domain NOMA (CD-NOMA). In PD-NOMA, multiple users are served opportunistically as per the channel conditions from a common orthogonal RB. On the other hand, in CD-NOMA, the code spreading sequences are used to serve different users. Different variants of NOMA in these two broad categories are explored and compared in this paper using various evaluation parameters in Section 3 and Section 4.

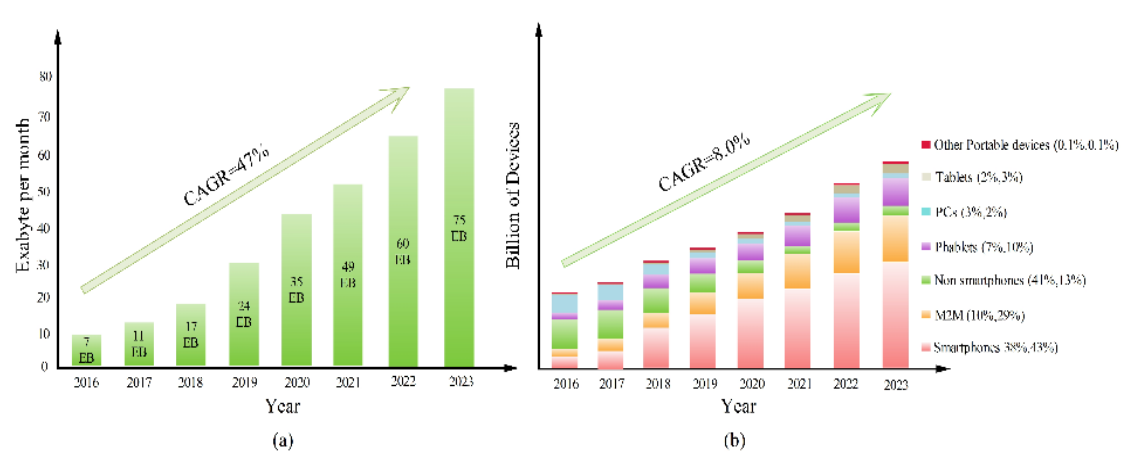

FIGURE 1: CISCO and Compound Annual Growth Report

A. SCOPE OF THIS SURVEY

Following are the existing related surveys from different authors addressing various aspects of NOMA [6]–[17]. Most of these surveys have focused either on CD-NOMA or PD-NOMA alone. But, to the best of our insight, no comprehensive survey considered both categories on a common platform. The proposed survey covers most of the variants of NOMA under two broad categories, PD-NOMA and CD-NOMA, for 5G networks. The existing survey articles are summarized as follows.

Yunzheng *et al.* [6] reviewed NOMA and waveform modulation schemes for 5G, but the authors do not describe the compatibility of NOMA with 5G. Islam *et al.* [7] surveyed the challenges and implementation issues of PD-NOMA and Liu *et al.* [8] conducted the same on theoretical issues but, the CD-NOMA was partially explored. Ding *et al.* [9], [10] discussed the applications, research, and future challenges of NOMA in 5G. Dai *et al.* [11] analyzed various challenges and solutions for NOMA, but the detailed classification of NOMA was missing in their survey article. Basharat *et al.* [12] focused on the MA schemes of NOMA for 5G and the discussion on various decoding methods. Aldababsa *et al.* [13] explored the uplink and downlink transmission models for NOMA with their extensions to MIMO and cooperative communication among different devices. Moreover, they discussed the important design challenges and approached for the downlink and uplink NOMA transmissions. But, they have not explored how the compatibility of NOMA with 5G techniques exists. Dai *et al.* [14] focused on PD-NOMA, CD-NOMA, as well as all 15 NOMA schemes under Rel.-14 3GPP NR. Also, they have explored NOMA for performance gain in different indoor and outdoor scenarios. However, the physical design issues of D2D communication were not explored by the authors. Cai *et al.* [15] explored various modulation techniques of OMA and different MA schemes of NOMA. They have focused on comparing different NOMA schemes and compared these based on various performance evaluation metrics. But, they have not explored the other challenging applications of NOMA such as D2D communication, M2M communication, and HetNets. Wang *et al.* [16] highlighted the design issues of various NOMA techniques for user separation. The authors focused only on the issues of latency, throughput in PD-NOMA and CD-NOMA. They have also elaborated spatial, hybrid, and network domains. Wu *et al.* [17] presented the technological requirements to enable CD-NOMA and explored its test cases in context with 5G networks. Still, they have not explored PD-NOMA and its compatibility in various 5G techniques. Table 3 presents a summary of these survey articles with key differences to the proposed survey article.

Fig. 2, Table 3, and Table 4 shows the related survey articles, which also highlights the research gaps in comparison to the proposed survey. The existing surveys on NOMA have mainly concentrated on the power domain and code domain. In this survey, we comprehensively studied the different variants of PD-NOMA and CD-NOMA proposed by different authors in context with 5G techniques applicable in various applications [18], [19], [20], [21], [22].

B. CONTRIBUTION OF THIS SURVEY

In this paper, we present a detailed review of NOMA techniques in 5G. We also highlighted various current challenges and issues for the implementation of various variants of PD-NOMA and CD-NOMA. Moreover, this paper highlights the inadequacy of existing 5G standards in achieving ultra-low latency. Based on the above discussion, the major contributions of this paper are as follows.

- We present a comprehensive review on the PD-NOMA and CD-NOMA to study the various challenges associated with them. The basic principle of NOMA and its standards, advantages, challenges, and solutions are studied.

TABLE 3: Comparison between the proposed and existing NOMA surveys

Year	**Authors**	**Brief**			**Power Domain**				**Code Domain**					
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
2015	Yunzheng et al. [6]	✓	×	×	×	×	×	×	MUSA	×	SCMA, PDMA	×	×	×
	Dia et al. [11]	✓	×	✓	✓	✓	×	SoDeMA	×	×	LDS-OFDM, LDS-CDMA, SCMA, PDMA	×	×	×
2016	Zhiqiang et al. [23]	✓	✓	×	✓	✓	x	MIMO	×	×	LDS-OFDM	×	×	×
	Wang et al. [24]	✓	×	✓	×	✓	✓	×	MUSA	RSMA	SCMA, PDMA	×	×	×
	Chunlin et al. [25]	×	×	×	×	×	×	mMTC	MUSA	RSMA	SCMA, PDMA	IDMA	×	×
2017	Ding et al. [10]	✓	×	✓	✓	✓	×	CC, MIMO, CR	×	×	×	×	×	×
	Ding et al. [9]	✓	×	×	✓	✓	×	CR, mmWave, MIMO,SISO, CC	NCMA	x	SCMA, PDMA, LDS	×	LPMA	×
	Islam et al. [7]	✓	x	×	✓	✓	×	CC, CoMP, VLC, SWIPT	×	×	×	×	×	×
	Liu et al. [8]	✓	✓	✓	✓	✓	×	D2D, MIMO, CC, SDN, HetNets, mmWave	×	×	LDS-OFDM, LDS-CDMA, SCMA, PDMA	IDMA	LPMA	×
	Basharat et al. [12]	✓	✓	×	×	✓	×	CR	MUSA		SCMA, PDMA, LDS	×	×	×
	Shan et al. [26]	✓	×	×	×	×	×	Hetxets	×	×	×	×	×	×
	Shirvanimogha et al. [27]	✓	×	×	×	×	×	M2M/IoT	×	×	×	×	×	×
	Di et al. [28]	✓	×	×	✓	✓	×	V2X	×	×	×	×	×	×
2018	Cai et al. [15]	✓	×	×	×	×	×	CC, CoMP, MIMO, CR	×	×	LDS-OFDM, LDS-CDMA, SCMA, PDMA	×	LPMA, BOMA	×
	Qi et al. [16]	✓	×	×	×	×	×	×	MUSA, NOCA, NCMA	RSMA	SCMA, PDMA	IGMA	×	×
	Aldababsa et al. [13]	✓	×	×	✓	✓	×	CC, MIMO	×	×	×	×	×	×
	Wu et al. [17]	✓	×	×	✓	×	×	×	MUSA, NOCA, NCMA, FDS, GOCA	RSMA, LSSA	LDS-OFDM, LDS-CDMA, SCMA, PDMA	IGMA, IDMA, LCRS	×	×
	Xiao et al. [29]	✓	×	×	×	×	×	mmWave	×	×	×	×	×	×
	Chandra et al. [30]	✓	×	×	×	×	×	mmWave	×	×	×	×	×	×
	Zhou et al. [31]	✓	×	×	×	×	×	CR	×	×	×	×	×	×
	Wan et al. [32]	✓	×	×	✓	✓	×	CC	×	×	×	×	×	×
	Ali et al. [33]	✓	×	×	✓	✓	×	CoMP	×	×	×	×	×	×
	Zhang et al. [34]	✓	×	×	×	×	×	HeUDNs	×	×	×	×	×	×
	Huang et al. [35]	✓	×	×	×	×	×	MIMO	×	×	×	×	×	×
	Zhong et al. [36]	✓	×	×	×	×	×	MIMO	×	×	×	×	×	×
	Ye et al. [37]	✓	✓	✓	✓	✓	✓	Grant-Free	MUSA, NOCA NCMA, FDS, GOCA	RSMA, LSSA	LDS-SVE SCMA, PDMA	IGMA, IDMA, LCRS	×	×
	Marshoud et al. [38]	✓	×	×	×	×	×	VLC	×	×	×	×	×	×
	Chen et al. [39]	✓	✓	✓	×	×	×	Grant-Free	×	×	×	×	×	×
	Dia et al. [14]	✓	✓	✓	✓	✓	✓	D2D, CoMP, CR, MIMO	MUSA, NOCA NCMA, FDS, GOCA, WSMA	RSMA, LSSA	LDS-OFDM, LDS-CDMA, SCMA, PDMA	IGMA, IDMA, LCRS	LPMA, BOMA	SAMA, SDMA
	S. M. R. Islam et al. [19]	×	×	×	×	✓	×	Resource Allocation for DL NOMA	×	×	×	×	×	×
	M. Mohammadkarimi et al. [18]	×	×	×	×	×	×	×	MUSA, NOCA NCMA, GOCA	RSMA	SCMA, PDMA	IGMA, IDMA, RDMA	×	×

Note- 1: Basics, 2: History, 3: Standards, 4: Capacity comparison, 5: DL/UL , 6: MUD Techniques, 7: Compatibility with 5G, 8: Spreading, 9: Scrambling, 10: Coding, 11: Interleaving, 12: Lattice & Beam, 13: Miscellaneous
Notations- ✓: Y, and ×: N

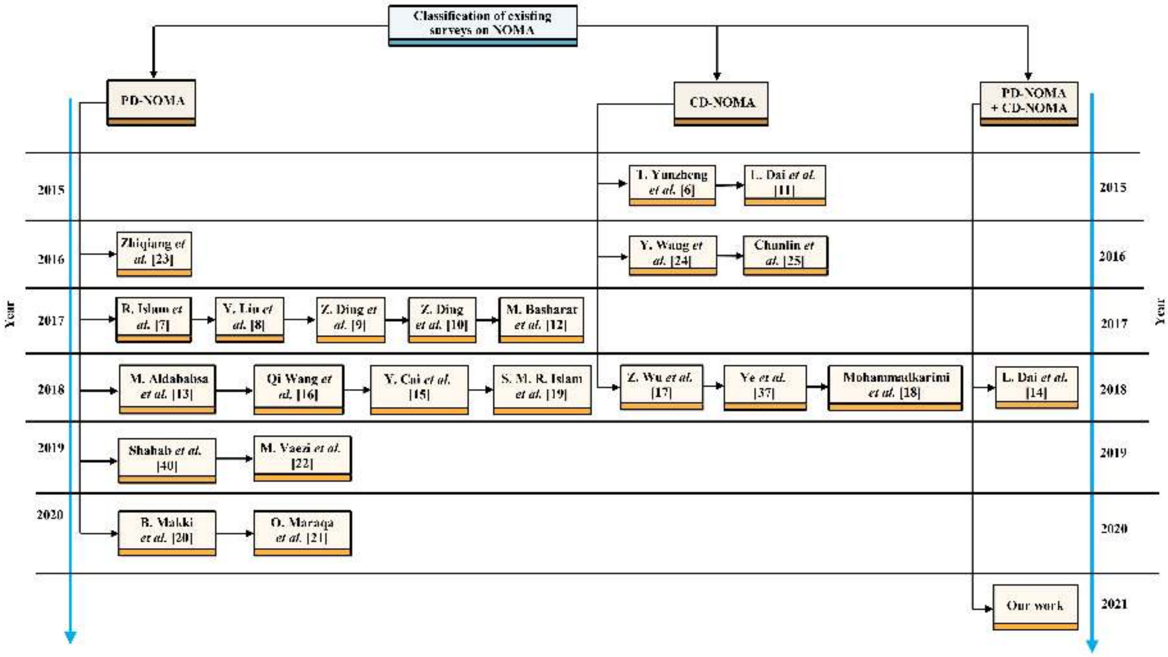

FIGURE 2: Classification of related surveys on NOMA

TABLE 4: Comparison between the proposed and existing NOMA surveys

Year	Authors	Brief			Power Domain				Code Domain					
		1	2	3	4	5	6	7	8	9	10	11	12	13
2019	Shahab et al. [40]	×	×	×	×	✓	×	×	MUSA, NOCA NCMA, FDS, GOCA, WSMA	RSMA, LSSA	LDS-SVE, LDS-OFDM, LDS-CDMA, SCMA, PDMA , SAMA	IGMA, IDMA, RDMA, LCRS	LPMA, BOMA BDMA	×
	M. Vaezi et al. [22]	×	×	×	×	×	×	D2D, CC, CoMP, CR, SWIPT, mMIMO, VLC, MEC, PLS, ML	×	×	×	×	×	×
2020	Shahab et al. [40]	×	×	×	×	✓	×	×	MUSA, NOCA NCMA, FDS, GOCA, WSMA	RSMA, LSSA	LDS-SVE, LDS-OFDM, LDS-CDMA, SCMA, PDMA , SAMA	IGMA, IDMA, RDMA, LCRS	LPMA, BOMA BDMA	×
2021	Our Work	✓	✓	✓	✓	✓	✓	D2D, CC, CoMP, CR, M2M, Grant-Free, SWIPT, WPCN, SISO, MISO, MIMO, mMIMO, VLC, V2X, UAV, MEC, WSN, UDN, UAC, PLS, THz, FD, AI, ML	MUSA, NOCA NCMA, FDS, GOCA, WSMA	RSMA, LSSA	LDS-SVE, LDS-OFDM, LDS-CDMA, SCMA, PDMA , SAMA	IGMA, IDMA, RDMA, LCRS	LPMA, BOMA BDMA	MDMA, PSMA, SOMA, RA-CEMA, TC-NOMA, PC-NOMA, GSOMA, BDM, NORA, SGMA

Note- 1: Basics, 2: History, 3: Standards, 4: Capacity comparison, 5: DL/UL , 6: MUD Techniques, 7: Compatibility with 5G, 8: Spreading, 9: Scrambling, 10: Coding, 11: Interleaving, 12: Lattice & Beam, 13: Miscellaneous
Notations- ✓: Y, and ×: N

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- We investigate how PD-NOMA improves the various features of 5G when it is integrated with its different applications. Furthermore, we also studied how PD-NOMA provides better results than previous multiple access techniques such as FDMA, TDMA, CDMA, and OFDMA.
- We also explore the concept of CD-NOMA and in-depth explain how the various variants of CD-NOMA support both the single-carrier and multi-carrier systems. Moreover, we also studied how the variants of CD-NOMA overcome the problems associated with the PD-NOMA.
- Finally, this paper discussed various challenges and open issues related to the PD-NOMA and the CD-NOMA. Along with this, we also discussed the potential solutions to overcome the challenges and open issues.

C. ORGANIZATION AND READING MAP

The structure of the survey article is as shown in Fig. 3. Table 1 and 2 lists all the acronyms used in the paper. The rest of the paper is organized as follows. Section II provides the background and history of NOMA. In Section III, we discussed PD-NOMA variants of 5G. In Section IV, we discussed the CD-NOMA variants usage in 5G. In Section V, we discussed the open issues and research challenges of NOMA, and finally, Section VI concludes the paper.

Fig. 4 also provides the reading map. Readers with interests in the basics of NOMA can focus on Sections I, II, and VI. Different NOMA variants used in 5G are given in Sections III and IV. Finally, Sections I, III, IV, and V are recommended to the readers interested in gaining a high-level overview of NOMA, including open research issues and challenges.

II. BACKGROUND AND HISTORY OF NOMA

This section discusses the background and history of NOMA. In each generation, there is a need for new MA techniques to allow users to reuse the spectrum simultaneously to have a high capacity by allocating the available bandwidth (or channel) among multiple users. This can be done in such a way that the QoS of users should not be degraded. In the first generation, a frequency division multiple access techniques (FDMA) was used in which frequency bands were divided into different channels, and each channel was allotted to different users. The second generation belongs to the global system for mobile (GSM) communications with Time-division multiple access (TDMA) techniques. Each user was allowed to transmit using a common frequency band but access the channel in a specific time slot. Moreover, this generation also supports code division multiple access (CDMA) technology known as IS-95 or cdmaOne. In the third generation, CDMA was used to uniform bandwidth with the same transmitted power. Users can transmit the data simultaneously using the same frequency band but with a specific pseudo-random code so that data can be retrieved by the specific user at the receiver side. In the fourth generation, the orthogonal frequency-division multiple access (OFDMA) technique was used, where MA was used by allocating the subsets of subcarriers to an individual user. So, the low-data-rate transmissions from different users are possible simultaneously. Using space division multiple access (SDMA) and MIMO technology, all the users can communicate simultaneously using the same channel. This multiple access scheme can be applied to satellite communication to improve the data rate. All the aforementioned MA techniques are shown in Fig. 5.

OMA schemes simplify the transceiver design and eliminate co-channel interference. However, the following limitations exist in these schemes. Firstly, the number of users served simultaneously is limited. Secondly, to maintain orthogonality, user scheduling along with strong feedback channels are required. Compared to OMA, NOMA is a better technique for RB allocation, optimizing joint power, code signature, and receiver layout. Also, the non-orthogonal behavior of NOMA decreases the scheduling of multi-user multiplexing and the requirement of a precise channel.

A. STANDARDS OF NOMA

It has been observed from the literature that when NOMA is integrated with eMBB, it improves the user fairness, multi-user capacity, and user experience in ultra-dense networks. On the other side, for mMTC and URRLC, NOMA resolves massive connectivity and a large coverage area requirement. It provides ultra-reliable link quality with low latency for contention-based grant-free transmission. By analyzing the aforementioned benefits of NOMA, 3GPP has developed various standards for both DL and UL scenarios described as follows.

1) NOMA standards for downlink

Multi-user superimposed transmission (MUST) was the first standard proposed by 3GPP for DL scenarios under LTE Release-13. According to the downlink applications, 3GPP divides the MUST scheme into three broad categories: MUST 1, MUST 2, and MUST 3. In MUST 1, coded bits of at least two users are mapped independently to construct the constellation symbols without relying upon the gray mapping. In MUST 2, coded bits of at least two users are mapped together to form the constellation symbols with gray mapping. However, MUST 3 is entirely different from MUST 1 and MUST 2.

2) NOMA standards for uplink

3GPP under Rel. 14 proposed fifteen NOMA schemes for the uplink scenario, which are as follows: SCMA, MUSA, LCRS, FDS, NCMA, PDMA, RSMA, IGMA, LDS-SVE, LSSA, NOCA, IDMA, RDMA, GOCA, WSMA, and NOMA. These schemes support massive connectivity, large link reliability, and low latency for mMTC to support a grant-free transmission. These schemes were simulated by different companies and predicted that these schemes' link-level and system-level simulation have higher throughput and gain than OMA techniques. Moreover, these schemes provide

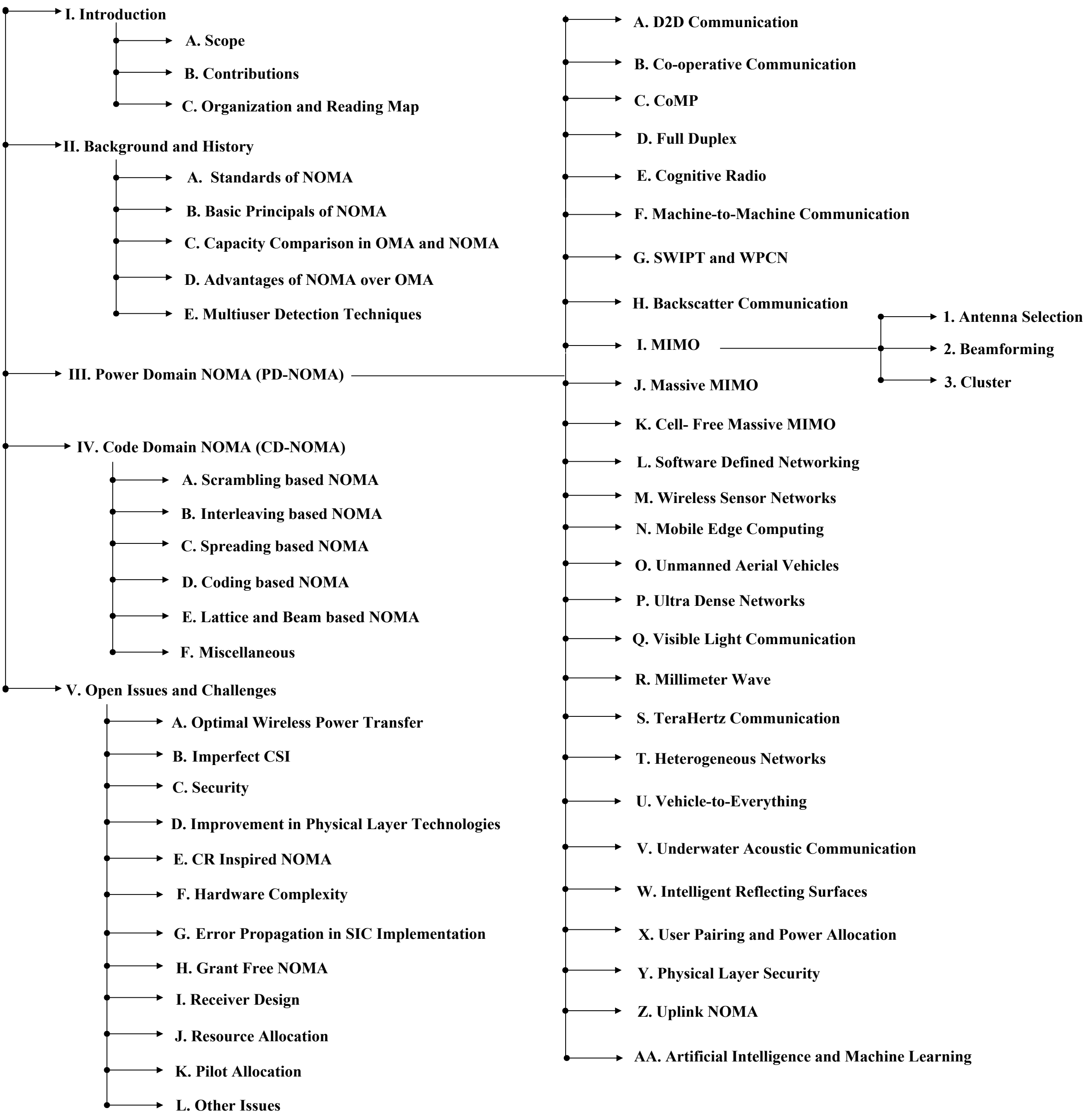


FIGURE 3: A detailed organization of the survey article

large sum-throughput, system capacity, and packet arrival rate (PAR). In Rel. 15, 3GPP proposed a new UL NOMA scheme which includes the signal processing at transmitter such that the receiver design supports multiple users.

B. BASIC PRINCIPLE OF NOMA

1) Downlink NOMA

In the DL scenario, the SC technique is applied at the transmitter side (the BS) to multiplex the signals. These signals have different power allocation coefficients. On the receiver side, a SIC technique is used to separate interfering signals. Power allocations coefficients are allocated as per the channel conditions of users. High power is allocated to the poor channel condition users, whereas low power is allocated to the better channel condition users as shown in Fig. 6.

2) Uplink NOMA

In an uplink scenario, each user's equipment (UE) transmit their signals towards the BS. Then, at the BS, SIC technique is used which separates the signals of UEs with their different

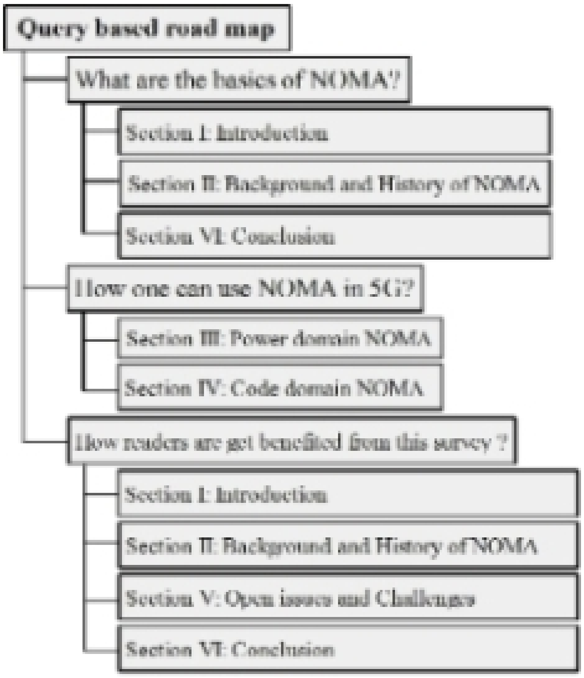


FIGURE 4: The reading map

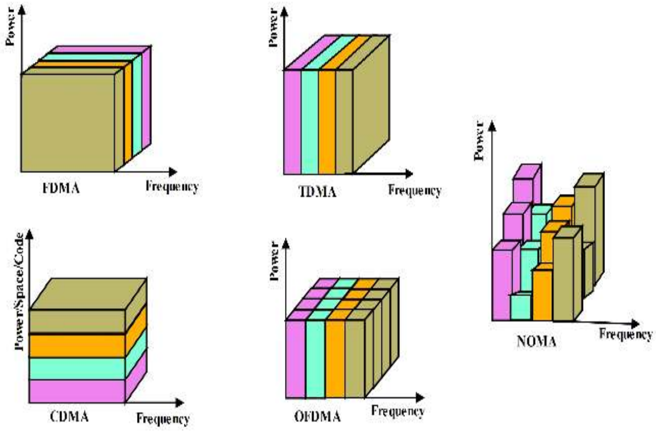


FIGURE 5: Different multiple access techniques

power allocation coefficients as shown in Fig. 6. The signal received at the BS can be represented as follows.

$$r_s = \sum_{p=1}^{N} h_p \sqrt{a_p P_m x_p} + \eta, \tag{1}$$

where r_s is the received signal, x_p is the transmitted signal, h_p is the channel gain, a_p is the power allocation coefficient, P_m is the transmitted power of the UE, and η is the additive white Gaussian noise (AWGN).

C. CAPACITY COMPARISON BETWEEN OMA AND NOMA

Fig. 7 represents the difference between OMA and NOMA.

1) OMA and NOMA

The mathematical formulation of OMA and NOMA is described as follows:

(a) OMA

The capacity of OMA according to the Shannon capacity theorem can be expressed as follows [41]:

$$C_p^{OMA} = b\log_2\left(1+\frac{a_p\rho}{b}|h_p|^2\right), \tag{2}$$

$$C_q^{OMA} = (1-b)\log_2\left(1+\frac{a_q\rho}{1-b}|h_q|^2\right), \tag{3}$$

where b is the RB allocation coefficients, ρ is the transmit signal-to-noise ratio (SNR) at the BS, a_p and a_q are the power allocation coefficients which satisfy $a_p + a_q \leq 1$, h_p and h_q are the channel gains.

In the absentia of power control at the BS, $\left(\frac{a_p}{b}\right) = \left(\frac{a_q}{1-b}\right) = 1$. So,

$$C_p^{OMA} = b\log_2\left(1+\rho|h_p|^2\right), \tag{4}$$

$$C_q^{OMA} = (1-b)\log_2\left(1+\rho|h_q|^2\right). \tag{5}$$

(b) NOMA

Compared to OMA, the Shannon capacity of NOMA can be expressed as follows:

$$C_p^{NOMA} = \log_2\left(1+\frac{a_p\rho|h_p|^2}{1+a_p\rho|h_p|^2}\right), \tag{6}$$

$$C_q^{NOMA} = \log_2\left(1+a_q\rho|h_q|^2\right). \tag{7}$$

When SNR becomes high, i.e., $\rho \longrightarrow \infty$ then

$$C_{sum,\infty}^{OMA} \approx \log_2\left(\rho\sqrt{|h_p|^2|h_q|^2}\right), \tag{8}$$

$$C_{sum,\infty}^{NOMA} = \log_2\left(\rho|h_q|^2\right). \tag{9}$$

So, the capacity sum gain of NOMA over OMA can be described as follows:

$$C_{sum,\infty}^{gain} = C_{sum,\infty}^{NOMA} - C_{sum,\infty}^{OMA}, \tag{10}$$

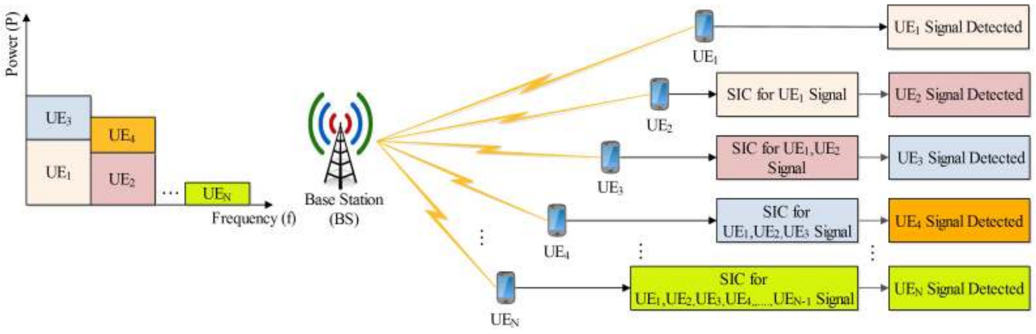
$$C_{sum,\infty}^{gain} = \frac{1}{2}\log_2\left(|h_p|^2|h_q|^2\right), \tag{11}$$

When $|h_q|^2 > |h_p|^2$, then capacity of NOMA becomes greater than OMA and this gain becomes more effective at a time when channel conditions of users becomes different. Authors in [42] mathematically proved that NOMA always outperformed the traditional OMA.

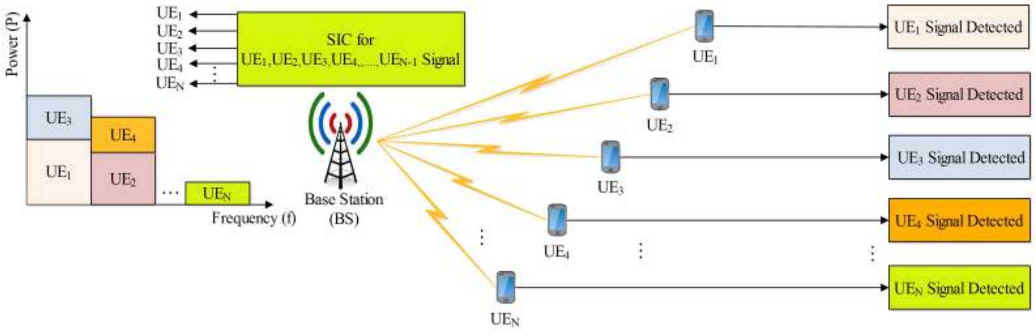
2) MIMO-OMA and MIMO-NOMA

The mathematical formulation of MIMO-OMA and MIMO-NOMA is given as follows:

(a) MIMO-OMA



(a) Downlink NOMA



(b) Uplink NOMA

FIGURE 6: Downlink and Uplink NOMA

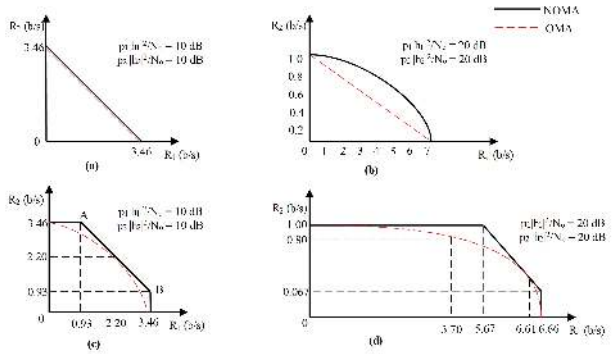


FIGURE 7: Difference between OMA and NOMA

According to [43], the capacity of MIMO-OMA in the m^{th} cluster is upper bounded which is given as follows:

$$C_{m,L}^{OMA}=\lambda_{(m,l)}\log_2\left(1+\sum_{l=1}^{L}\rho\Omega_{(m,l)}|v_{(m,l)}^{H}H_{(m,l)}p_m|^2\right) \tag{12}$$

where $\lambda_{m,l}=\frac{\Omega_{(m,l)}|v_{(m,l)}^{H}H_{(m,l)}p_m|^2}{\sum_{k=1}^{L}\Omega_{(m,k)}|v_{(m,k)}^{H}H_{(m,k)}p_m|^2}$, $l=\{1,2,\ldots,L\}$. Here, $H_{m,l}$ is the channel matrix, p_m is the power of the m^{th} cluster, and $v_{(m,l)}$ is the detection vector on the received signal.

(b) MIMO-NOMA

The capacity for the m^{th} cluster in MIMO-NOMA is given as follows [43]:

$$C_{m,L}^{NOMA}=$$

$$\sum_{l=1}^{L}\log_2\left(1+\frac{\rho\Omega_{(m,l)}|v_{(m,l)}^{H}H_{(m,l)}p_m|^2}{1+\rho\sum_{k=1}^{L}\Omega_{(m,k)}|v_{(m,k)}^{H}H_{(m,k)}p_m|^2}\right) \tag{13}$$

where $\rho=\frac{1}{\sigma_n^2}$, σ_n^2 is the noise variance.

For any power split in MIMO-OMA, a larger capacity can be achieved by MIMO-NOMA via assigning the same power split to the latter. In particular, when the power split is optimal for MIMO-OMA, a larger capacity can be achieved by MIMO-NOMA.

D. ADVANTAGES OF NOMA OVER OMA

This section discusses the benefits of NOMA over OMA as follows.

- *High SE:* NOMA provides high SE compared to OMA because, in NOMA, multiple users acquire the services through each RB, whereas in OMA, one RB is allocated to each user, which results in wastage of bandwidth [44]. Moreover, NOMA can be easily integrated with other 5G technologies such as mMIMO, mmWave, HetNets, D2D, and CR, to enhance the network's throughput.
- *Massive connectivity:* NOMA has the abilities to support billion of smart devices using its non-orthogonal

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characteristics. It is suitable for both the IoT [27], and Tactile Internet [45] because packets are smaller in size and sporadically in nature. In NOMA, multiple devices get the services through a single RB by using SC, whereas, in OMA, one device acquires one RB, resulting in the wastage of RBs.

- *Fairness:* NOMA provides fairness among users, so a large amount of power is allocated to the weak users (having poor channel conditions) and lesser to the strong users. Then, both strong and weak users have guaranteed QoS in terms of throughput. To achieve better fairness among different users, the authors in [46] provide fair power allocation schemes. Co-operative communication and CoMP also play a vital role in enhancing the QoS of the weak users in terms of their fairness [33], [47]. Furthermore, to improve the fairness among users, the power allocation scheme was proposed in [48] assuming average CSI at the transmitter.
- *Ultra Low Latency:* In 5G, latency requirements are more stringent due to the heterogeneous network (HetNet) architecture. OMA techniques are not suitable for such architecture because they depend on access-grant requests, increasing transmission latency and signaling overhead. In LTE, access grant request takes 15.5ms when data is transmitted [49]. To resolve it, NOMA is used, which supports grant-free transmission, especially in the UL scenario. Moreover, NOMA also provides flexible scheduling among many devices as per the need for application and QoS of devices.

E. MULTI-USER DETECTION TECHNIQUES

These techniques separate the multi-user signals shared over the same resources. Classification of multi-user detection techniques is as shown in Fig. 8. Brief description of these techniques are as follows:

1) The minimum mean square error-successive interference cancellation (MMSE-SIC)

It is an enhanced version of the MMSE receiver, where information bits are decoded from those user's signal which is having the highest signal-to-interference noise ratio (SINR) among all the signals. Then, the signals of those users are reconstructed and cancelled from the received signals. This process is repeated continuously until the correct signal stream is recovered successfully. Then, the receiver suffers from the problem of error propagation which degrades the QoS of the users. To mitigate it, an SINR difference between the data streams of different users in each round must be sufficiently large to make the receiver suitable for those NOMA schemes that depend upon the diversified channel conditions.

2) Message Passing Algorithm (MPA)

It depends on the non-linear symbol detection scheme. Its structure comprises sparse spreading sequences having the performance equivalent of maximum-likelihood (ML). It performs the most reliable detection on every resource element to transfer the symbols to the neighboring elements. The MPA receiver uses the symbol level detection but did not use error correction of forwarding error corrections (FECs) to detect the variable data streams. This problem can be resolved by combining MPA with turbo codes and SIC, respectively. In MPA-turbo, the data of MPA is given to the FEC for decoding, which is collected as the extrinsic information. Compared to MPA-turbo, MPA-SIC eliminates the multi-user interference (MUI) from the received signals.

3) Estimation propagation algorithm (EPA)

It is implemented at the receiver to reduce the computational complexity and to support SCMA [50]. It was based on the variation approximate inference method used in the machine learning era [51].

4) Elementary signal estimation-parallel interference cancellation (ESE-PIC)

It was first implemented in interleave-division multiple access (IDMA) to handle many multiplexed users to have a robust performance. In this technique, first, ESE detects the transmitted symbols using a linear symbol detector, and then at the same time, the detected symbol de-interleaved to achieve a high gain. Finally, the information received at the decoder is returned to the ESE module for symbol detection.

III. POWER DOMAIN NOMA (PD-NOMA)

This section describes the various variants of PD-NOMA used in 5G as shown in Fig. 9. PD-NOMA is a technique that serves multiple users' simultaneously through the same subchannel by allocating different power levels to them. This technique is mainly used in 5G to improve the SE, EE and reduce the latency. The detailed description of each variant of PD-NOMA is discussed in the following subsections.

A. D2D COMMUNICATION

D2D is used to enhance local area services, and its advantages in 5G are as follows; i) to enhance the EE by supporting low power proximity service, ii) to enhance the SE by sharing radio resources with CUs, iii) to support various peer-to-peer (P2P) services, iv) to offload the traffic from the BSs, and v) to reduce latency. However, inter-user and co-channel interference exists due to the RB reuse, which degrades the QoS of the CUs and D2Ds users. Hence, it decreases the SE of the communication system. To overcome this issue, researchers integrate NOMA with D2D in 5G. Moreover, it also manages the inter-user interference among the D2D users due to SIC, as shown in Fig. 10. To fully exploit the benefits of D2D with NOMA, various NOMA-based schemes were proposed, which are discussed as follows.

1) MTBSA [52]

In this scheme, the authors proposed the subchannel allocation algorithm based on the many-to-one matching game

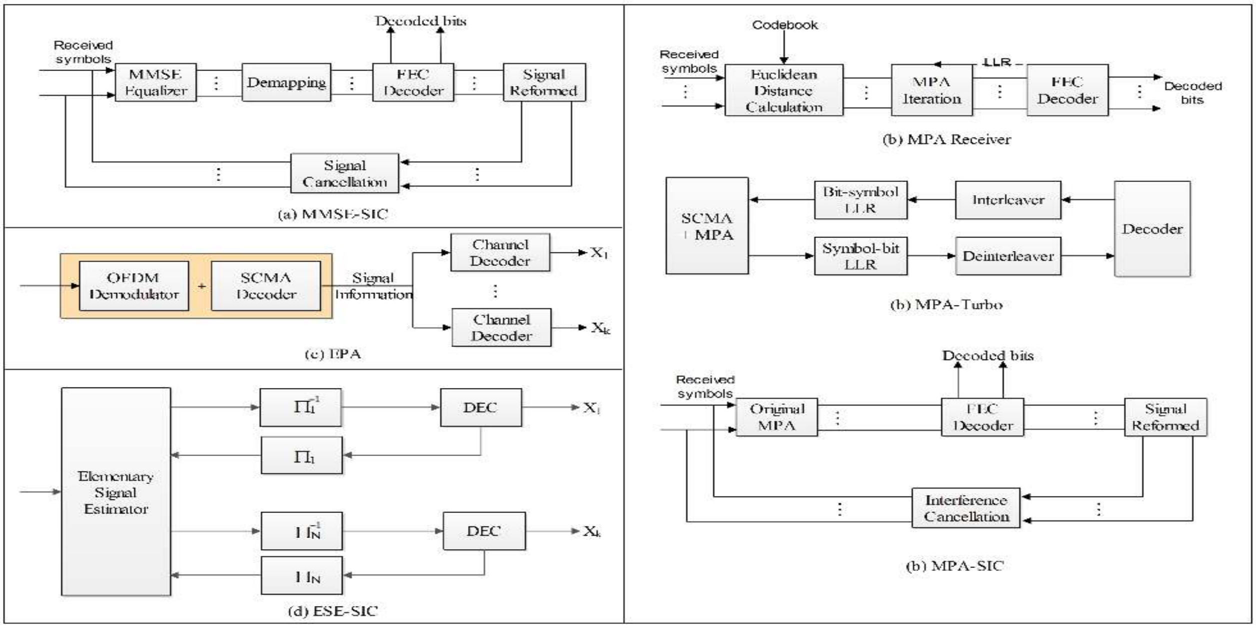

FIGURE 8: Classification of multiuser detection techniques

to overcome the issue of an inter-channel interference in an uplink situation [52]. This scheme reduces the system complexity up to $O(NM^2)$ and provides stable matching between subchannels and D2D groups. As the number of D2D groups increases, this scheme provides better performance. Moreover, this scheme is also used to measure the sum rate and provides a good sum rate compared to the one-to-one matching algorithm and traditional OMA-based D2D groups.

2) Q-NOMA [53]

It is for in-band D2D group communication in the cellular overlay network, where clusters of D2D receivers (DRs) are randomly distributed around D2D transmitters (DTs) [53]. In this technique, DTs are located as per the Gaussian point process model to obtain user clustering and spatial separation. It provides a better trade-off between analytical tractability and modelling accuracy. Based on interference approximation results, the authors in [53] demonstrated two closed-form expressions for the outage probability of DRs using stochastic geometry: (i) by varying coverage radius RD, and (ii) distance between probe DRs and DTs. Performance of Q-NOMA in D2D group communication provides better accuracy and overall less outage probability than conventional paired D2D communication using OMA.

3) DBIRA [54]

It is a dual-based iterative resource allocation algorithm (DBIRA) used to reduce the co-channel interference that arises due to the sharing of the same spectrum between the D2D pairs and the CUs [54]. It enhances the sum rate of the D2D pairs with the minimum data-rate requirements of the CUs. The authors used the Okumura-Hata model for simulation and compared the result of DBIRA with the MCU-OFDMA scheme. Moreover, they described the convergence behavior of the DBIRA algorithm and found a better sum rate. The simulation result proved that the DBIRA algorithm performs better than MCU-OFDMA in the presence of interference. Moreover, it provides a high sum rate for the D2D pairs even if the CUs required large transmit power.

4) NOMA-MCIK [55]

In this, the authors combined the NOMA with the MCIK techniques for proper usage of power and subcarrier index dimensions to reduce the error with a high diversity order. Different sub-carriers were provided to each user, due to which interference among D2D under dense deployed areas becomes limited. Its performance was found good in terms of an instantaneous and average pairwise error probability (PEP) over the Rayleigh fading channel. It achieved an acceptable accuracy level of 1dB over high SNR regions for an average PEP.

5) NOMA-OPT [56]

In this, the authors studied a joint time allocation and power control algorithm that was a combination of energy harvesting and NOMA. It has low complexity of an order of $O(LK^2 + LKlog_2\frac{1}{\epsilon})$. Moreover, it was used to improve the EE of the D2D users with the condition to provide guaranteed

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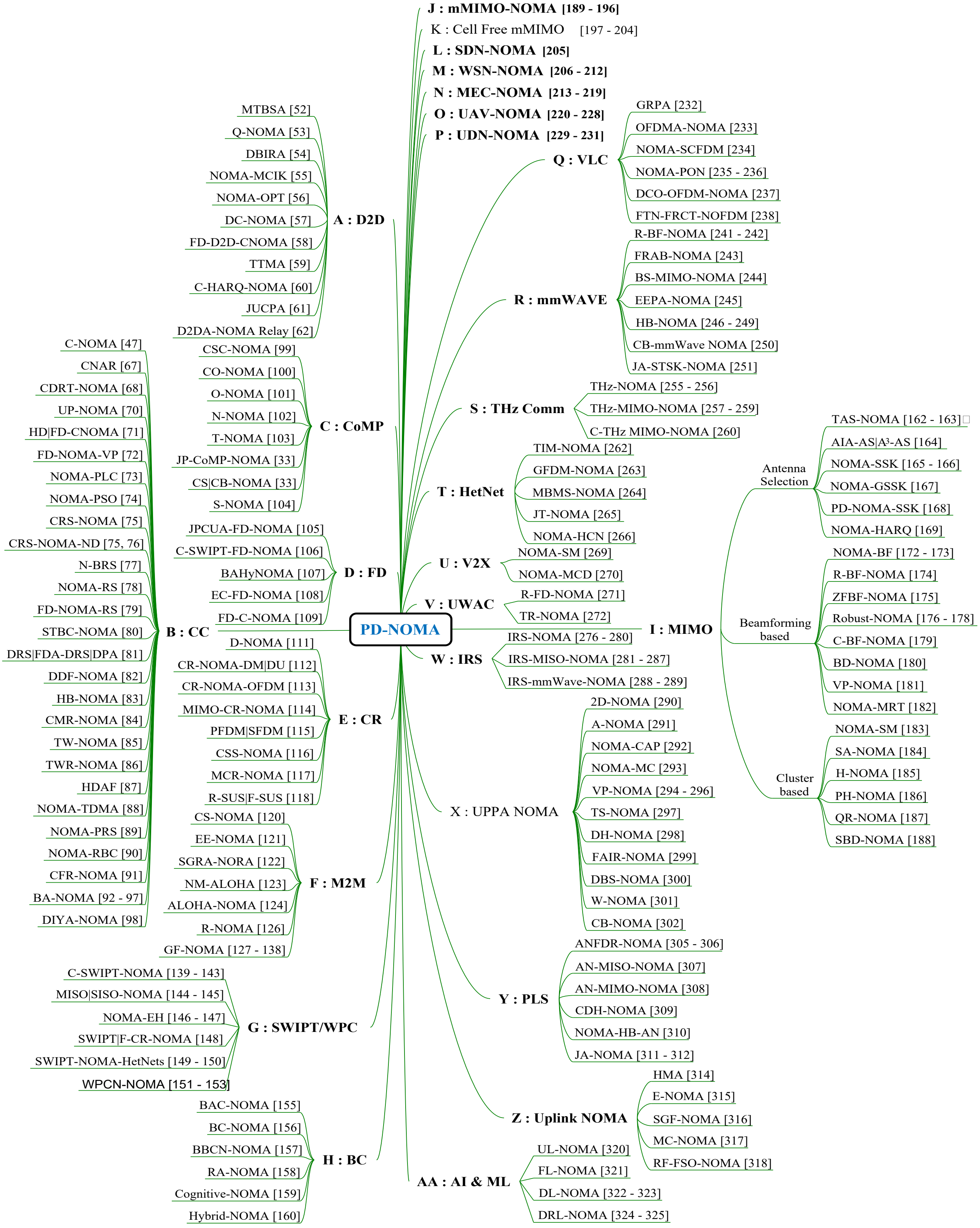

FIGURE 9: A taxonomy of PD-NOMA variants

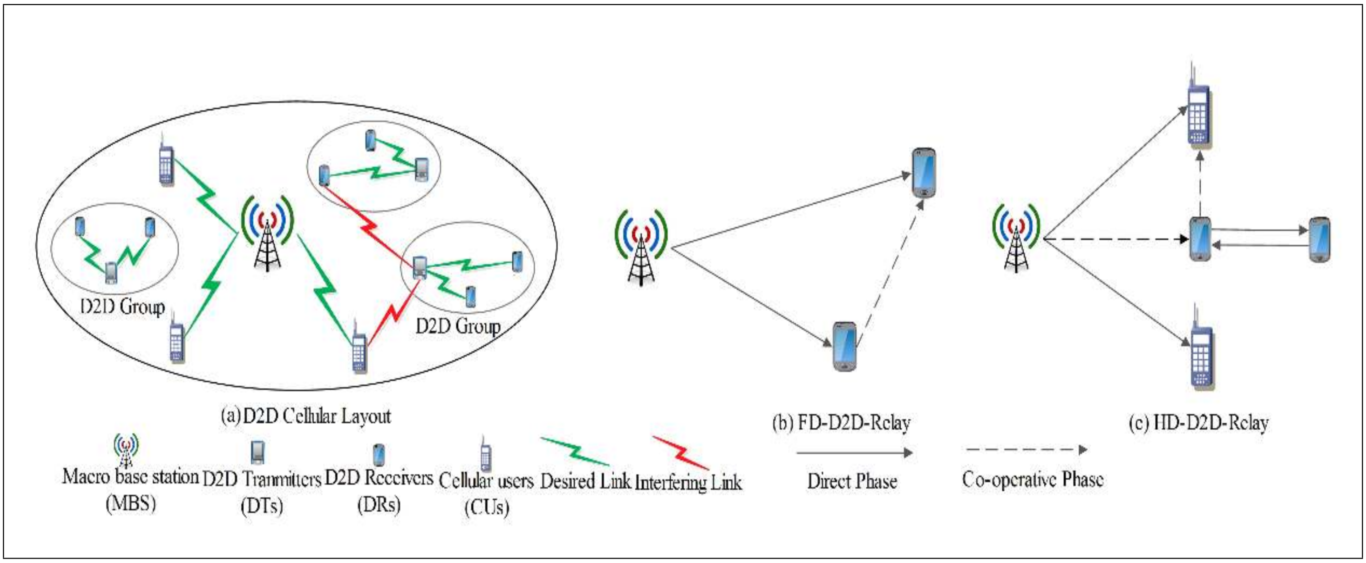

FIGURE 10: D2D-NOMA

QoS to the CUs. In this algorithm, both the CUs and the D2D transmitters harvest the energy from a hybrid access point (HAP). It solves two problems of D2D underlaying cellular network: (i) Low system throughput due to limited battery life of users, and (ii) Low data rates of an individual user due to the limited resource of TDMA. These problems were solved by an optimal power allocation of the CUs from the given power of the D2D transmitter. Then, based on optimal conditions, a globally optimal solution was proposed for the D2D in the closed-form in terms of power and time resources.

6) DC-NOMA [57]

Kim *et al.* proposed a D2D aided cooperative relaying NOMA scheme (C-NOMA) to improve the SE of the system. It gives an effective method to embrace the non-orthogonal D2D transmission at the relay to have a high sum rate in comparison to the conventional NOMA and C-OMA. Moreover, it provides the sum capacity of the order of $\log SNR$. On the other hand, when a constant power is allocated for superposition coding, DC-NOMA achieves an upper bound scaling capacity of $\frac{1}{2}\log SNR$. The results show that it achieves high ergodic capacity as compared to that of conventional NOMA and C-OMA.

7) FD-D2D-CNOMA [58]

In this, the authors proposed the FD D2D aided cooperative NOMA scheme, where user pairs are predefined, and the FD technique is used with the NOMA strong users. The FD technique at the NOMA-strong users collected the data sent by the BS and transferred it to the NOMA-weak users over the same frequency band. So, the outage performance of the NOMA-weak user improves by reducing the cooperative delay. To improve the performance of this scheme in terms of OP, adaptive multiple access (AMA) scheme was also proposed. It enables the BS to dynamically switch power among the FD-D2D-CNOMA, conventional NOMA, and OMA.

8) TTMMA [59]

Lim *et al.* proposed a NOMA based technique for peer discovery of distributed D2D communication. The performance metrics of peer discovery are range and capacity. To improve the discovery capacity, the authors in [59] explored the non-orthogonal resource allocation. They generated a single tone transmission signal used to solve the problem of the peak to average power ratio (PAPR). To design the discovery procedure concisely, it removed the strict collision detection and collision avoidance problems. The authors also proposed a message-passing algorithm with supplementary schemes for multi-user detection of superimposed multi-access signals. It permits a certain number of mobile stations (MSs) to regulate and transmit their signals on a similar resource section to enhance the discovery capacity. TTMMA with message passing algorithm enhances the number of discovered devices up to 1.5 times more than the conventional FDMA-based discovery from the same resources.

9) Cooperative HARQ assisted NOMA [60]

In this, the authors proposed an interference-aware mathematical scheme based on stochastic geometry for large-scale D2D networks. The utilization of stochastic geometry combines the spatial interference correlation at the NOMA receivers and temporal interference co-relation at the HARQ transmission side. The authors also proved that when aggregated interference and spatial and temporal interference are ignored, it overestimates and generates misleading design insight. The performance of this scheme was analyzed in terms of outage and throughput limited by up to two users.

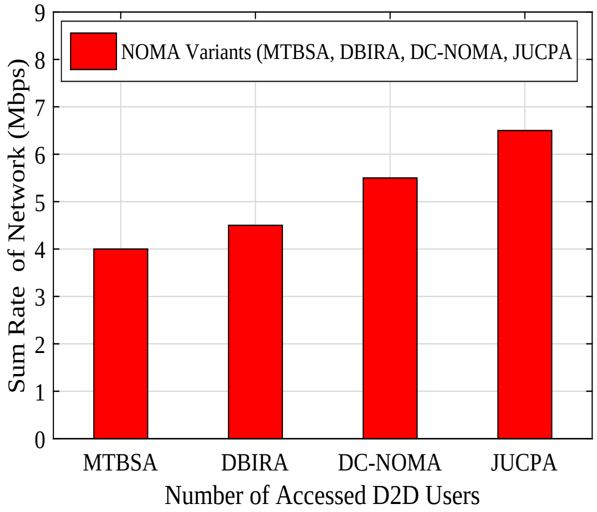

FIGURE 11: Comparison of various NOMA schemes for D2D communication

The above assumption of channel gain difference was not always true for the NOMA-based D2D scenario. D2D receivers are clustered around D2D transmitters and are situated in proximity of each other. As a result, they have almost similar channel conditions. It achieved a 32% lower outage probability than non-cooperative HARQ assisted NOMA and 47% improvement in long-term average throughput (LTAT) compared to HARQ assisted OMA.

10) JUCPA [61]

Kazmi *et al.* proposed a scheme to mitigate the problem of user clustering and power allocation, where the NOMA technique was applied at the BS. The proposed scheme protects the CUs from interference and enhances the sum rate of the D2D pairs. The authors formulated the problem as a mixed-integer non-linear NP-hard problem. To solve it, the authors divided the problems into two subcategories. In the first category, matching game theory was used for user clustering and subchannel allocation. A many-to-one matching game is proposed for user clustering, one-to-many matching theory, and subchannel allocation. In the second category, complementary geometric programming was used to pertain to the power of the D2D transmitters (DTs). It has 70% and 90% higher execution gains of the average sum rate in comparison to NOMA and OFDMA, respectively. Furthermore, it improved the network connectivity to serve a large number of users through the same RBs.

11) D2D assisted NOMA Relay [62]

In this, a NOMA technique was integrated with D2D UEs for remote UEs. Due to the utilization of fewer resources, it provides improved SE and a high data rate for the farthest UEs compared to the traditional D2D relay schemes.

12) Comparison of existing NOMA schemes based on D2D communication

- Table 5 provides the detailed relative comparison of existing variants of NOMA used in D2D communication using the parameters such as transmission scenario, the technique used, merits, open issues, throughput, EE, PEP, and PARP.
- A comparison of various NOMA schemes for D2D communication is shown in Fig. 11. The system model, parameters, and environment used in the simulation are chosen from [61]. Fig. 11 shows that the JUCPA achieves 18.2%, 44.45%, and 62.5% higher sum rate as compared to the MTBSA, DBIRA, and DC-NOMA with an increase in the number of accessed D2D users. The JUCPA reduced the co-channel interference among the D2D pairs using the SIC. Also, the computational complexity achieved by JUCPA is much lower than MTBSA, DBIRA, and DC-NOMA. These two reasons depict that JUCPA is more suitable for D2D communication as compared to other ones.

B. COOPERATIVE COMMUNICATION

Cooperative communication uses one or multiple relays to enhance the signal strength between the source and destination. It uses two-time frames such that in the first frame, direct phase transmission is used while relays use the second frame to forward the information from relays to the final destinations, as shown in Fig. 12. It has many advantages due to the following reasons [63], [64]; i) enlarges the coverage area, ii) enhances the system capacity, iii) reduces the effect of multipath fading, iv) resolves the difficulty to mount multiple antennas on small size terminals, and v) improves the QoS of cell edge users (CEUs). In this technique, relays use two types of protocols, decode and forward (DF) and amplify and forward (AF), to transfer the information from source to destination. According to the relaying operation, relays are categorized as half-duplex (HD) and full-duplex (FD). In HD, two-time slots and frequency bands are used for data transmission and reception, while in FD, a one-time slot and the same frequency band is used [65]. Moreover, the usage of FD increases the SE as compared to HD [66].

To improve the SE of the network, researchers used NOMA with cooperative communication. This integration provides benefits such as reduce system redundancy, fairness, and improved diversity gain for weak users. Considering the aforementioned advantages, the authors have proposed different variants of cooperative NOMA discussed in the sequel.

1) C-NOMA [47]

In this, the authors analyzed the diversity gain to exploit the prior information of the NOMA technique. In this technique, a strong user (having better channel condition) decodes the messages of other users and acts as a relay for weak users (having poor channel condition) to enhance their reception reliability. It improves the diversity gain for all users. Still,

TABLE 5: Parametric analysis of existing NOMA schemes based on D2D

Problem in D2D	**NOMA Variant**	**Transmission scenario**	**Techniques**	**Performance metrics**							**Merits**	**Open issues**
				1	**2**	**3**	**4**	**5**	**6**	**7**		
Co-channel interference	MTBSA [52]	Downlink	Joint subchannel and power allocation	✓	×	×	×	×	×	×	Higher sum rate and stable state	Reduced receiver complexity
Co-channel interference	Q-NOMA [53]	Downlink	Power allocation	×	✓	×	×	×	×	×	OP reduced	Can be extended to MIMO systems
Resource Allocation	DBIRA [54]	Downlink	Power control and channel assignment	✓	×	×	×	×	×	×	Higher data rate	Imperfect CSI
Energy and Interference	NOMA-MCIK [55]	Downlink	Joint power control and sub-carrier index activation	×	×	×	×	✓	×	×	Increase the diversity gain and improve CEUs performance	Analyse OP and compute SE by using different detection techniques
Energy harvesting	NOMA-OPT [56]	Downlink/ Uplink	Joint power control and time allocation	×	×	×	✓	×	×	×	Improved EE	Can be extended for multicell network
Capacity scaling	DC-NOMA [57]	Downlink	Power allocation	×	×	×	×	×	×	✓	Higher SE than OMA in low SNR regime	Relay selection needs to be explored
Residual interference & quality of channels	FD-D2D-CNOMA [58]	Downlink	Co-operation	×	✓	×	×	×	×	×	OP reduced and AMA increase the gain	Reduces the complexity
Collision avoidance & detection	TTMMA [59]	NA	Message passing modulation algortihm	×	×	×	×	×	✓	×	Increased the capacity	Proximity services need to be improved
Interbeam & co-channel interference	C-HARQ-NOMA [60]	Downlink	User grouping and power control	×	×	✓	×	×	×	×	Mitigate the interference, improved throughput and reduced OP	Imperfect CSI and Nakagami-m fading channel can be explored
Resource Allocation	JUCPA [61]	Downlink	Joint user clustering and power allocation	✓	×	×	×	×	×	×	Mitigate the interference and improved network connectivity	Imperfect CSI
Resource allocation	D2D-relay-NOMA [62]	Downlink	Relaying	✓	✓	×	×	×	×	×	Time slot space reduced upto half and all users achieve diversity order of K	User grouping needs to be explored more

Note- 1: Sum rate, 2: OP, 3: Throughput, 4: EE, 5: PEP , 6: PAPR, 7:Ergodic sum capacity
Notations- ✓: Y, and ×: N

during the cooperative phase, it has been observed that when the data is transmitted from the relay to the weak user, it took extra time slots to fulfill the target because relaying operation is carried out serially. A user pairing scheme was used to reduce the complexity of C-NOMA.

2) Collaborative NOMA Assisted Relaying [67]

In this, the collaborative NOMA assisted relaying (CNAR) was proposed for 5G, which consists of two NOMA links, which are known as collaborative source-relay (S-R) and relay-destination (R-D). Here, the message of the relay was taken from the S-R NOMA signal, and power is adjusted to transmit the remaining part to cell-edge users of the R-D link. In this scheme, relay signals are transmitted and received in a specific frequency band. To achieve high throughput and support many users, the FD mode was used in the twofold antenna relay system for the S-R and the R-D links. In addition to this, the interference was avoided by using separate authorized and unauthorized bands. The execution of the framework was analyzed for OP and ergodic sum capacity. The simulated results show that the proposed framework provides better OP and ergodic sum capacity than OMA. However, it is suitable for short-range communication such as Bluetooth, UWB. Hence, to overcome this problem and to fully exploit the potential benefits of C-NOMA, dedicated relays are proposed with NOMA.

3) CDRT-NOMA [68]

In this, the authors used NOMA in CDRT, where they can communicate directly or indirectly with the BS. To cancel the interference, a NOMA inherent property is used to take the information from other UEs. Its performance was analyzed for OP over frequency flat block fading channels by using DF relaying. In contrast, to [68], the authors in [69] analyzed the performance of the above scenario using AF relaying.

4) UP-NOMA [70]

The authors in this proposed a CDRT protocol using uplink NOMA based on the two-user scenario. In this protocol, a cell center user communicates directly with the BS, whereas CEUs use HD DF relay to communicate with the BS. Authors analyzed the performance of their scheme in perfect and imperfect SIC scenarios by measuring the ergodic sum capacity.

5) HD-CNOMA/FD-CNOMA [71]

Liu *et al.* proposed a hybrid HD/FD scheme for C-NOMA to resolve the problem of power allocation and to maximize the achievable user rate. In addition to this, a relay selection scheme was also proposed for multiple users. Moreover, an optimal power was allocated by the execution of NOMA-HD and NOMA-FD. It outperformed conventional NOMA, HD-CNOMA, and FD-CNOMA schemes.

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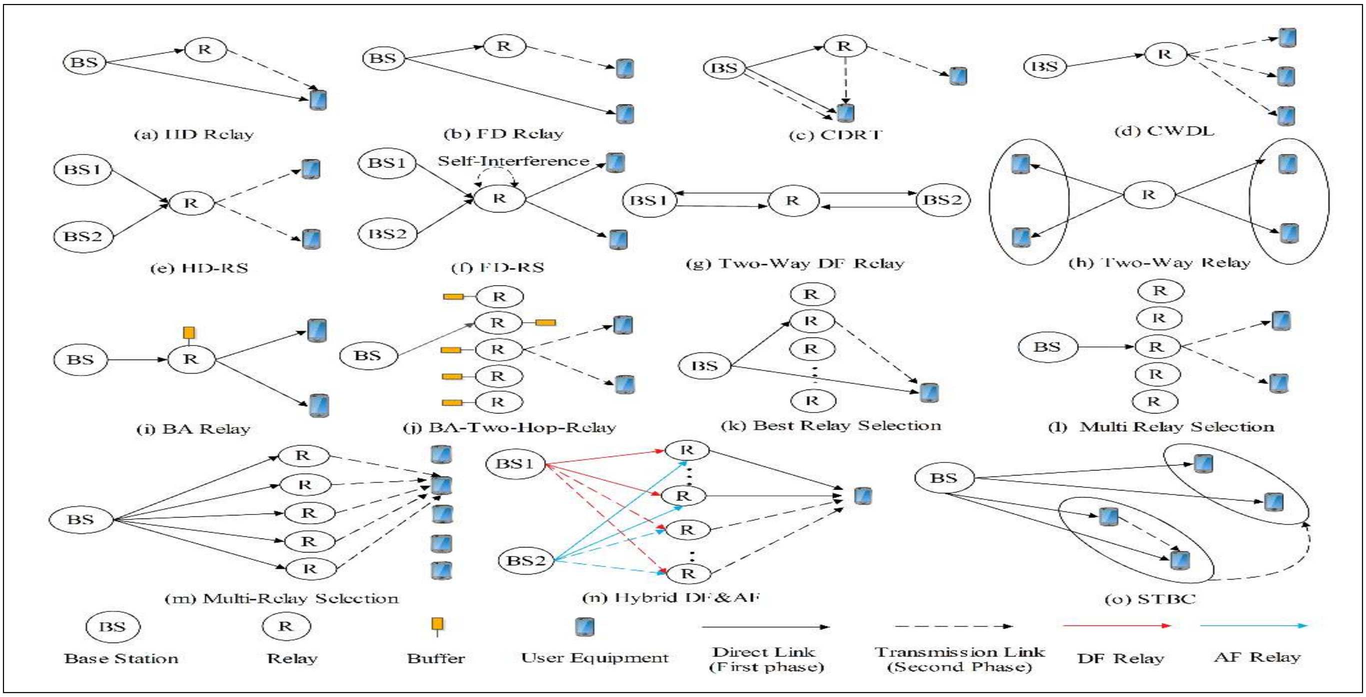

FIGURE 12: Cooperative Communication/Cooperative Relaying systems

6) FD-NOMA-VP [72]

In this, the P nearest and the Q farthest users having similar gain are divided into distinct NOMA clusters using a relay. Clustering was performed using the virtual pairing (VP) scheme between one nearest and multiple farthest users over non-overlapping frequency bands. In FD-NOMA-VP, a dedicated FD relay was used to maintain the communication between the farthest users and the BS whereas, the nearest user communicates directly with the BS. The execution of the proposed framework is analyzed for OP, ergodic sum capacity (ESC), and outage sum potential in conjunction with analytical derivations for each perfect and imperfect interference cancellation (IC) technique. FD-NOMA-VP achieved tremendous performance gain in comparison to the conventional MA schemes in perfect IC. On the other side, at imperfect IC, the performance degrades due to an increase in the impact of residual interference at the relays.

7) NOMA-PLC [73]

It is a two-stage power allocation NOMA scheme. In the first stage, the source modem transmits two data symbols with different power allocation factors while both the relay and destination receive the superposition coded signal. Then, the destination decodes the signal with a higher power while treating the other as noise. At the relay, the higher power signal is decoded and then cancelled using the SIC to obtain the second symbol. In the second stage, assuming that it is successfully decoded, the relay forwards the second symbol to the destination. The performance of the system was analyzed in terms of the average sum capacity. Two advantages of using the NOMA in PLC are: (i) reduced transmit power at PLC modems which relaxes the electromagnetic compatibility (EMC) problem associated with PLCs, and (ii) better fairness among users since it allows to transmit multiple signals simultaneously to different users (PLC modems) with each user occupying the entire bandwidth.

8) NOMA-PSO [74]

It is applied to the OFDM-based cooperative SATCOM systems to avoid the wasting of resources such as frequency and energy. In [74], NOMA is applied to a multi-satellite cooperative transmission system consisting of GEO and LEO satellites. Due to the presence of NOMA, GEO and the LEO satellites communicate simultaneously to multiple ground users locating in the overlapped coverage area of the satellites. In this case, channel gains from a user to GEO and LEO satellites can be significantly different, making it feasible and reasonable to apply NOMA to the cooperative system. The authors used the particle swarm optimization (PSO) algorithm and concluded that the performance of their scheme was better than OMA in SATCOM.

9) CRS-NOMA [75]

Kim *et al.* proposed a spatially multiplexed transmissions scheme to enhance the SE. The authors analyzed the achievable average rate for an independent Rayleigh fading channel which shows a better performance of CRS-NOMA as compared to the traditional DF scheme.

10) CRS-NOMA-ND [75]

It was based on novel receiver design. Generally, the source simultaneously transmits two symbols by using the superposition code, and the relay decodes and forwards the symbols with lower allocated power by using SIC [75]. But, in [76], the destination jointly decodes two symbols from both the directed signal and then forward the signal by using the maximum-ratio combination and SIC. The result of this scheme shows that it outperforms the other schemes for parameters such as ergodic capacity and outage probability when the S-to-R link is better than the R-to-D link.

11) N-BRS [77]

In this, multiple relays are used instead of single, which is an extended version of CRS-NOMA. Among multiple relays, the best relay is selected because the best relay selection (BRS) reduces overhead and complexity while achieves the full diversity order even in the presence of a finite number of interference sources. The performance of this scheme was analyzed in terms of the average rate under an independent Rayleigh fading channel. Its simulated results show that N-BRS has more rate gain than the conventional BRS (C-BRS) when the number of relays becomes large.

12) NOMA-RS/HD-NOMA-RS [78]

This scheme uses NOMA with the HD relay, which uses the dual-hop cooperative relaying. In this scheme, a parallel collaboration between two sources was observed to achieve their objectives. In [78], after acquiring the transmitted symbols in parallel by both the sources with exclusive assigned powers, the relay forwards a superposition coded composite sign using NOMA. The advantage of NOMA-RS is that it has multiple sources in contrast to CRS-NOMA and CRS-NOMA-ND. Results demonstrated that NOMA-RS has a high capacity gain in residual interference and imperfect SIC compared to conventional NOMA under perfect SIC.

13) FD-NOMA-RS [79]

It consists of FD NOMA and cooperative relay such that two source-destination pairs have a common FDR [79]. FDR demultiplex these symbols and simultaneously transmits a superimposed composite signal to the end locations with a processing delay tau using downlink NOMA. They evaluated the performance of their scheme for ESC, OP, and outage sum capacity. To prove the effectiveness of their scheme, they analytically analyzed their scheme by using both perfect and imperfect SIC conditions. Simulation results of the proposed scheme reveal that it outperforms the HD-NOMA-RS and HD-OMA-RS and improves the 5G systems' performance compared to the HD scheme.

14) STBC-NOMA [80]

It is a two-phase cooperative DF relaying scheme which is based on Alamouti (2x1 multiple-input single-output mode) space-time block coded (STBC-NOMA) [80]. To examine the performance of this scheme, a closed-form solution for ergodic sum capacity and outage probability over independent Rayleigh fading channels was studied. At a high SNR, asymptotic approximations for E-SC, OP, and O-SC were also manifested. It acquired significant performance gain using NOMA and the traditional DF relaying schemes compared to the conventional CRS.

15) DRS-FPA and DRS-DPA [81]

These are DF dual relay selection schemes that use distributive space-time coding for cooperative NOMA [81]. In the DRS-FPA scheme, the fixed power is allocated to the system. One relay demultiplexes both the signals of U1 and U2, and finally, the max-min criterion is used to select the best relay. In DRS-DPA, the dynamic power allocation-based DF dual relay selection scheme was used, where DPA was used for both hops instead of the second hop only. The performance of both schemes was evaluated in terms of a closed-form expression of OP.

16) DDF-NOMA [82]

It is a cooperative NOMA scheme that uses dynamic decode-and-forward (DDF) relay to increase the reception reliability of spatially random users. In DDF-NOMA [82], the user who is close to the BS demultiplexes the superimposed mixture of the users' signals received from the BS using partial reception and then transmits the signal to the farthest user. To overcome the need of channel state information at the BS, random user pairing was used, where users were randomly paired to carried out NOMA transmission with one-bit feedback.

17) HB-NOMA [83]

This scheme uses the benefits of NOMA and TDMA at the relay to improve the throughput of poor channel condition users' [83]. Using the optimum throughput from HB-NOMA relay for each mobile user (MU), the authors investigated the scenario of multi-MUs. To maximize the utility of all MUs in a multi-MUs scenario, the concept of Gradient-projection (GP)-based multi-MUs scheduling was used. The authors concluded that the GP scheduling scheme improves the total utility of MUs compared to the round-robin (RR) scheduling scheme.

18) CMR-NOMA [84]

It is a cooperative multi-relay NOMA-based scheme, where the information of each user in the system is relayed by all other users in an interference-free manner [84]. It establishes cooperation among the users clustered in a NOMA structure. In the cooperation phase, users receive a replica of their signal sequentially, starting from the weakest user. It enhances the overall system performance compared to NOMA and CNOMA schemes at the expense of detecting more signals and adding an extra time slot. Moreover, the authors proposed a modified SIC technique to reduce the computational complexity at the receiving UEs.

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19) TW-NOMA [85]

It is a two-way DF NOMA scheme, in which an intermediate relay helps two source nodes to communicate with each other [85]. In this scheme, the authors integrated the digital network coding (DNC) to compress received data from these source nodes. Its performance was analyzed and evaluated for OP over Rayleigh fading channels. Simulation results show that TW-NOMA outperformed the conventional two-way scheme using DNC (TWDNC), two-way scheme without using DNC (TWNDNC), and two-way scheme in AF relay systems (TWANC).

20) TWR-NOMA [86]

It is a two-way relay NOMA system where two different NOMA groups exchange messages among each other using HD-DF relay [86]. The effect of both the perfect and imperfect SIC was taken to compute the SINR of users. The authors evaluated the closed-form expressions of OP users' signals in terms of the exact and asymptotic way using both the perfect and imperfect SIC. The main aim of this scheme was to provide the solution for decoding order errors due to perfect SIC. The impact of an interference signal (IS) at relays in high SNR regimes and zero diversity order was also studied. The numerical results show that the proposed scheme under perfect SIC and in the absence of IS has a larger sum-rate than TWR-OMA systems.

21) HDAF [87]

In this, the authors proposed a hybrid relaying scheme consisting of two sources and one UE. In this scheme, some of the relays worked on the principle of the DF protocol and others on the AF protocol. Improved sum channel capacity and average system throughput were achieved from this scheme compared to the traditional schemes.

22) NOMA-TDMA [88]

In this, the authors investigated the outage performance over two different NOMA relaying schemes, cooperative NOMA and TDMA-NOMA. In this proposal, two relays have been used between the BS and users. The cooperative NOMA took two-time slots, whereas the NOMA-TDMA took three-time slots to complete one round of communication. Here, NOMA and dirty parity coding (DPC) are used in the first and second-time slots, respectively. On the other hand, in NOMA-TDMA, NOMA was used in the first time slot, and TDMA was used in the second and third time slots. Moreover, the authors explored the impact of error propagation in NOMA SIC, and it provides better OP than NOMA-TDMA.

23) NOMA-PRS [89]

The authors in this investigated the performance of cooperative NOMA with the AF and partial relay selection (PRS) technique. In this scheme, the BS communicates with two users using a selected relay and directly links with the users. The results show that when the number of relays increases, its performance increases, but the performance gain becomes constant after two relays at the high SNR region.

24) NOMA-RBC [90]

In this, one BS and two users were used to analyze the performance of cooperative SISO-NOMA relaying. In this proposal, users near the BS employed the compress and forward protocol and acted as an FD relay for the farthest users. The performance of this scheme is analyzed in terms of the achievable rate region of an RBC with the compress-and-forward (CF) relaying and noisy network coding (NNC). From the obtained achievable rate region with CF and NNC, a DPC is also applied at the BS to enhance its performance. It has better results as compared to conventional NOMA.

25) CFR-NOMA (Cooperative full-duplex relaying) [91]

This is an in-band FD relaying scheme with imperfect SIC. In [91], users near the BS act as the FD relay for the far users. The numerical results of this scheme were analyzed in three conditions using the parameters such as OP and ESC under three conditions. In the first condition, the power of relays and the BS were kept fixed. In the second condition, the power of the BS and relay are optimized to reduce the OP. In the third condition, fairness between the users was taken into account, and the power of both the BS and relays was optimized to maximize the individual rate of users.

26) BA-NOMA [92]

Relays transmit and receive the data packets when S-R and R-D links are in outage [92] in buffer aided (BA)-NOMA. It improves the reliability of the relaying systems, which increases the throughput of the system. Xia *et al.* [93] proposed a centralized mechanism to select the best relay to exchange the buffer state information between the relay until it becomes empty. Moreover, the authors in [94] proposed a buffer-aided relaying technique that contains one source and two users. In comparison to [94], the authors in [95] proposed a NOMA relay network, where a dedicated relay was used to transmit the information to two users. Using the same scenario of [95], the authors in [96] used an adaptive transmission scheme for a single relay network to maximize the throughput of the cooperative NOMA system to serve two users concurrently. In [97], the authors proposed a multi-relay topology and determined the power allocation coefficient. Moreover, they proposed two relay selection algorithms Delay-Aware NOMA (DA-NOMA) and Delay and Diversity-Aware NOMA (DDA-NOMA).

27) DIYA-NOMA [98]

It is a scheme used to improve the network coverage and throughput to provide the quality of service and quality of experience to the end-users by reducing the delay and interference. The authors in this proposed the Tactile Internet (TI) driven delay assessment for D2D communication, which works in two phases to achieve the goal. In the first phase, a full-duplex communication at relays (intermediate nodes)

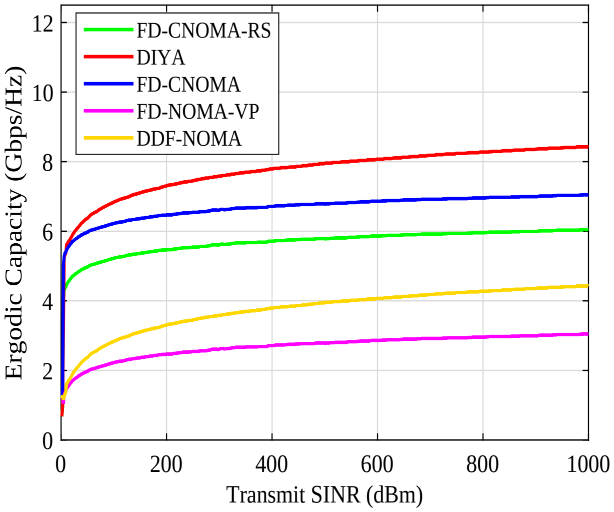

FIGURE 13: Comparison of existing NOMA schemes on Cooperative Communication

is used to simultaneously have the first- and second-hop transmission in the same time slot. Then, TI-based communication is used at the D2D transmitter to increase the speed of transmission. In the second phase, pricing-based three-dimensional (3-D) matching is proposed to improve the throughput of the cell edge users and the mitigation of co-channel interference. Also, the power of the D2D transmitter is optimized using successive convex approximation with low complexity, which converts the non-convex optimization problem of subchannel allocation and power control into a convex problem.

28) Comparison of existing NOMA schemes based on cooperative communication

- Table 6 provides the detailed relative comparison of existing variants of NOMA used in the D2D communication with reference to parameters such as transmission scenario, the technique used, merits, open issues, throughput, EE, PEP, and PAPR.
- Fig. 13 represents the effect on the ergodic capacity (EC) with respect to transmit SINR. The system model, parameters, and environment used in the simulation are chosen from [79]. The graph shows that when SINR is low, the EC of the network increases rapidly, but as the graph move towards the high transmits SINR region, the EC becomes constant. This happened because as the SINR increases, the effect of intra-user interference increases. Thus, the result shows DIYA outperforms as compared to FD-CNOMA, FD-CNOMA-RS, FD-NOMA-VP, and DDF-NOMA. Moreover, it is evaluated that at 600 dBm, the DIYA provides approximately 40% and 45% higher EC as compared to the FD-NOMA VP and DDF-NOMA schemes, respectively. This means that DIYA is more suitable for cooperative communications in the 5G networks.

C. COMP

CoMP is an inter-cell technology designed for LTE/LTE-A, which enhances the throughput of the users located at the edges of a cell. In this technology, CEUs get the services from the users of the same cell and the users of other cells via cooperation with each other. This technique reduces inter-cell interference via sharing the information of users that are using the same channel. However, sharing the same channel by many users of different cells affects the SE of the network. This decrease in SE motivates researchers to integrate NOMA with CoMP, which is a challenging issue due to the following reasons: (i) scheduling the APs (or the BS) and users for the application of the NOMA strategy, (ii) co-channel interference in a multi-cell scenario, and (iii) SIC complexity of NOMA. To resolve these issues, the researchers propose different variants of NOMA, which are discussed as follows.

1) CSC-NOMA [99]

In this, the authors proposed a coordinated superposition coding (CSC) scheme in the CoMP network to overcome the issue of not utilizing the same channel by the CEUs and the users nearest to the APs. In this scheme, the superposition algorithm is used for DL transmission through which both the CEUs and the users nearest to the APs can access the common channel. To achieve it, an Alamouti code (space time code) is transmitted using the NOMA technique among the CEUs and the users nearest to the APs. Then, the SE of the CoMP network also increases. This scheme outperformed the coherent transmission schemes and has a lower backhaul overhead for the users located at the edges of a cell.

2) CO-NOMA [100]

It is a resource allocation technique for mobile networks, i.e. when NOMA is combined with CoMP, it provides two advantages: (i) a large number of users got the services from limited resources and (ii) less time is taken by the packets to be delivered from source to destination [100]. In this technique, NOMA uses the space domain multiplexing using an appropriate power distribution among user pairs, and it combines with it using a coordinated transmission from several RRUs. The upper bound worst-case complexity of this scheme per cluster per RB is given as follows: $O(((K2^{(K-1)} - 1)c_{\phi} + c_{eval})|U(c)|)$. With an increase in the number of active users in this scheme, the throughput per access also increases linearly.

3) O-NOMA [101]

Tian *et al.* proposed Opportunistic-NOMA (O-NOMA) to improve the capacity of the CoMP-network which reduces the complexity of the SIC decoding process. Its topology is based on the APs broadcast signal, AP selection, and its cell area. This scheme is divided into two cases: the ideal and non-ideal cases. In the ideal case, each user selects only one AP as per its preferred set, while in the non-ideal case, cells overlap with each other, and users may select multiple APs. It

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TABLE 6: Relative comparison of existing NOMA schemes based on cooperative communication

Problem in cooperative NOMA	**NOMA Variant**	**Performance Metric**	**Advantages**	**Open Issues**
QoS of far users	C-NOMA [47]	Outage Probability (OP) and ergodic sum capacity	1) Reduce the system complexity, 2) maximizes the diversity gain, 3) Improves reception reliability of poor connections	1) Multi-antenna at BS, 2) optimal power allocation in cooperative NOMA need to be studied.
Multiple CEUs cannot served concurrently	CNAR [67]	Outage probability and Ergodic sum capacity	1) Cell edge users achieved guaranteed data rate, 2) Provides high throughput	Effect of NOMA interference on CEUs needs to be examined.
Acquiring side information for interference cancellation	CDRT-NOMA [68]	Outage probability and Ergodic sum capacity	1) Imroves the SE, 2) capacity gain increases	Can be extended to multicell scenario to achieve high capacity gain.
Capacity gain	UP-NOMA [70]	Ergodic sum capacity	Boost the system capacity for next generation wireless network	Scheme needs to be tested using Nakagami-m Fading channel.
Power allocation	FD/HD-CNOMA [71]	User rate	Maximizes the achievable user rate for the sake of fairness	Resource Allocation scheme need to be designed for the proposed scenario.
Interference cancellation	FD-NOMA-VP [72]	Outage probability, Outage Capacity and Ergodic sum capacity	Provides better results than other pairing schemes	Can be extended for MIMO systems to improve the throughput.
Average Capacity	NOMA-PLC [73]	Average Sum Capacity	1) Reduces the electromagnetic compatibility associated with PLC, 2) Relay forwards the two symbols	1) AF protocol need to be examined, 2) Can be extended to FD system.
Limited frequency and energy resources in SATCOM	NOMA-PSO [74]	Sum Rate	This scheme integrates with OFDM based cooperative SATCOM system to avoid wasting resources consisting GEO and LEO satellites	Can be extended to mMIMO systems.
Spatially multiplexed transmissions	CRS-NOMA [75]	Average rate	1) Improves the average channel power of the S-R links, 2) Acquires two data symbols during two time slots	Time slots need to be reduced.
Receiver Design	CRS-NOMA-ND [76]	Ergodic sum rate and Outage performance	1) Provides better Ergodic sum rate than CRS, 2) MRC scheme is applied at receiver side	Incremental redundancy techniques and source transmission at the second phase need to be studied
Average Rate gain	N-BRS [77]	Average Rate	Reduces overhead and complexity	Best relay position and channel gain need to be examined.
SIC performed for different users	NOMA-RS/HD-NOMA-RS [78]	Ergodic sum capacity	Large number of users can be served at the same time	Outage Probability needs to be evaluated
Spectral efficiency loss in a HD protocol	FD-NOMA-RS [79]	Ergodic sum capacity, Outage probability and Outage sum capacity	Large number of users can be served through the same frequency band	More insights are required for MIMO-NOMA
Spectral efficiency and reliability	STBC-NOMA [80]	Ergodic sum capacity and outage probability	1) Boosts the SE, 2) Increases the system reliability	The usage of multiple antenna at the receiver side and its computation complexity using a mathematical analysis needs to be studied
Diversity gain	DRS-FPA/DRS-DPA-NOMA [81]	Outage Probability	1) Improves the system performance, 2) Provides high diversity gain using dual relay	Need to study this scheme for Nakagami-m fading channels
Reception reliability of CEUs	DDF-NOMA [82]	Outage Probability	Improves the reception reliability of spatial domain users	This scheme needs to be explored for alternative user pairing strategies exploiting limited CSI knowledge.
Impact of weak channel power gain	HB-NOMA [83]	Throughput	Increases the throughput upto 30% as compared to TDMA	Needs to be investigated in the situation in which different relays select different MUs to provide relay-transmission within a same time-slot.
QoS of strong users	CMR-NOMA [84]	BER and Ergodic sum rate	Modified SIC technique is used to reduce the computational complexity of the receiving UEs	1) Scheme can be extended for MIMO systems, 2) It can be evaluated for imperfect CSI.
Spectral Efficiency at Relays	TW-NOMA [85]	Sum Outage probability	1) Two way DF relay with NOMA is used, 2) Provides lower outage probability than TWDNC and TWANC, 3) Achieved better performance locate the relay at two suboptimal points between the source nodes	1) Rician and Nakagami-m Fading channels, 2) Imperfect CSI
Residual Interference Signal	TWR-NOMA [86]	Ergodic rate, EE, OP, Delay-tolerant throughput	1) Provides larger rate in absence of SIC at the relay, 2) Provides higher throughput with imperfect SIC	Nakagami-m fading channel can be explored.
Channel capacity	HDAF-NOMA [87]	Channel capacity and Average system Throughput	It is used to enhance the channel capacity and system throughput for multiple relays	Scheme need to examined over Nakagami-m fding channels.
Outage Performance	NOMA-TDMA [88]	Outage Probability	1) Less Interference, 2) SIC error propagation is considered	1) The time slots for transmission can be reduced, 2) Power allocation factor can be optimized.
PRS effect	NOMA-PRS [89]	Sum rate, Outage probability, and Ergodic capacity	1) Improved the sum rate and user fairness, 2) Performance gain increases with the number of relays.	Can be extended to multiple users
Effect of full duplex relaying	NOMA-RBC [90]	Achievable Throughput	1) Improved the weak user rate, 2) Larger gain is achieved using Dirty parity coding and compress-and-forward.	Can be extended to MU-MIMO system
Inband full duplex relaying and Imperfect SIC	CFR-NOMA [91]	Outage probability, ergodic sum rate and Power allocation optimization	1) Near users treated as a full duplex relay for the far users, 2) Fairness is examined, 3) Maximizes the achievable rate of users	Channel allocation scheme can be explored.
Reliability of relays	BA-NOMA [92]- [97]	Throughput and Outage probability	Improves the QoS and data rate of the Cell edge users	Relay selection can be done more accurately.
Delay and Interference	DIYA-NOMA [98]	Sum Rate and Delay	Improve the coverage network and throughput of the cell edge users	Extend to multi-cell scenario.

performs better in terms of OP and the sum rate as compared to JT-NOMA.

4) N-NOMA [102]

It is a technique used for downlink CoMP network with randomly deployed users, which consists of SC and distributed analog beamforming at the APs [102]. The SC used by both the CEUs and users nearest to the APs, while distributed analog beamforming enhances the QoS of the users located at the edges of a cell. Analog beamforming was used for two reasons: i) it reduces the system overhead, and ii) it utilizes the spatial degree of freedom more efficiently than STBC without using CSI. Its performance was analyzed in terms of closed-form OP because the error probability of detection was tightly bounded, and evaluated the outage capacity efficiently. Moreover, they also resolved two challenges: (i) SINR arises due to SC and distributed analog beamforming, and (ii) to capture the impact of random user locations.

5) Multi-Tier NOMA (T-NOMA) [103]

It is a threshold-based multi-tier cluster scheduling strategy [103] which enhances the QoS of the CEUs (poor channel condition). Its model is based on the non-ideal scenario, i.e., the APs cannot serve all users in the CoMP network. In this strategy, the users who the APs directly serve are treated as the transmission nodes. These transmission nodes forward a signal to the users who APs cannot serve. Then, the clusters are divided into different tiers. In the first tier, the clusters are directly served by the APs, whereas in the second tier, the transmission nodes served users in the other clusters, and the same process continues in the other tiers. The signals forwarded by the transmission nodes are based on the channel conditions of the nodes and users they served.

6) JP-CoMP-NOMA [33]

In JP-CoMP-NOMA, data is shared between more than one BSs. Based on services provided to users from the active BSs, it is classified into two classes: JT-CoMP-NOMA and DCS-CoMP-NOMA [33]. In JT-CoMP-NOMA, multiple BSs have served both the CEUs and the CCUs using the same RB without interference. Hence, it enhances the signal strength for CEUs, but at the cost of a decrease in the rate for CCUs. An organized superposition coding scheme is used for DL to reduce the CSI sharing overhead to handle it. Then, the common CEUs among the two cells get the Alamouti coded signals from two BSs while the CCUs get the services from their corresponding BS. JT-NOMA enhances the transmission rates for CEUs without sacrificing the rates for CCUs. In DCS-CoMP-NOMA, the user's data is shared between multiple BSs, but transmitted from the selected BS's only. In DCS NOMA, as per order statistics transmitting, the BS dynamically changes over time and provides service to the CEUs, increasing the transmission rate.

7) CS/CB-CoMP-NOMA [33]

In this variant, BSs do not share user's data, but they exchange CSI and cooperative scheduling data using an interface X2. Moreover, adjacent BSs do not transmit a superimpose message to NOMA users but transmits a dedicated message to CCUs to ensure data rates for CEUs. Moreover, it improves the QoS of CoMP-NOMA users and provides guaranteed data rates for CEUs. In CB-CoMP-NOMA, only the serving BS has a user's data and is based on global CSI, and a beamforming decision is made with coordination. To remove the inter-channel interference (ICI), two Interference Alignment algorithms were proposed called an interfering channel assignment (ICA)-CB and interference alignment (IA)-CB. The first algorithm requires global CSI at the BS, while the second needs the knowledge of CEUs serving channels at the BS. For the second one, a substantial number of antennas are required to reduce the interfering channels information.

8) S-NOMA [104]

In this, the authors proposed S-NOMA to enhance the security of the physical layer for NOMA-CoMP transmission. They proposed the combination of coordinated user-scheduling and joint transmission strategy to minimize information leakage. This scheme protects the target user from untrusted users during the NOMA transmission process. The simulation demonstrates that S-NOMA provides better secrecy OP and sum rate as compared to conventional NOMA.

9) Comparison of existing NOMA schemes based on CoMP

- Table 7 provides the detailed relative comparison of existing variants of NOMA used in CoMP concerning parameters such as the transmission scenario, technique used, merits, open issues, throughput, SE, PEP, and PARP.
- Fig. 14 illustrates the comparison between energy efficiency and spectral efficiency. The system model, parameters, and environment used in the simulation are taken from [33]. From the Fig. 14 it is observed that JT-CoMP-NOMA achieves the best energy efficiency because it involves several base stations for transmission. For the conventional system, the signal generated by neighboring BS will become interference, affecting the received signal strength. However, for JT-CoMP-NOMA, it utilizes the neighboring BSs to assist in its transmission process. In addition, it mitigates the interference and converts it into a meaningful signal, which helps to improve the signal strength.

D. FULL DUPLEX

Full-duplex (FD) is a technique in which data can be transmitted and received simultaneously over the same resource block and time. Despite this advantage, this technique suffers from self-residual interference (SRI). To overcome this issue, researchers integrate NOMA with FD. This integration alleviates the problem of SRI and improves the SE, EE, delay,

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TABLE 7: Relative comparison of existing NOMA schemes based on CoMP

Problem in CoMP	**NOMA Variant**	**Transmission scenario**	**Techniques**	**Performance metrics**							**Merits**
				1	**2**	**3**	**4**	**5**	**6**	**7**	
Sharing of same channel between the cell edge and CCUs	CSC-NOMA [99]	Downlink	Almouti code integrated with APs	✓	×	×	×	×	×	×	Reduces the backhaul overhead for CEUs and improves the reception reliability of CEUs
Inter-cell Interference	CO-NOMA [100]	Downlink	Distributed power allocation	×	×	✓	×	×	×	×	Large number of users can be served and packet travel time from source to destination decreases
Multiuser Interference	O-NOMA [101]	Downlink	Joint muti-cell power allocation	✓	✓	×	×	×	×	×	Mitigates the complexity of SIC, enlarges the system throughput and overcome the muti-user interference
All the users can be served by atleast one AP	T-NOMA [103]	Downlink	Threshold based multi-tier cluster scheduling	✓	✓	×	×	×	×	×	Improves the QoS of the users having very poor channel conditions
Sharing of same channel between the cell edge and CCUs	N-NOMA [102]	Downlink	Fixed power allocation	×	✓	×	×	×	×	×	Improved EE
Inter-cell Interference	JT-CoMP-NOMA [33]	Downlink	Distributed power allocation (Beamforming with known CSI)	×	×	✓	✓	×	×	×	Improves the QoS of CEUs
Inter-cell Interference	CS-CoMP-NOMA [33]	Downlink	Distributed power allocation (Coopertive scheduling with known CSI)	×	×	✓	✓	×	×	×	Reduces the overhead for high mobility CEUs and users data are not shared among the BSs
Inter-cell Interference& detection	CB-CoMP-NOMA [33]	Downlink	Distributed power allocation (Beamforming)	×	×	✓	✓	×	×	×	Reduces the overhead for high mobility CEUs and users data are not shared among the BSs
Inter-cell Interference	DPS-CoMP-NOMA [33]	Downlink	Dynamic point selection (User clustering and power allocation)	×	×	✓	✓	×	×	×	Improved the QoS of the CEUs

Note- 1: Sum rate, 2: OP, 3: Throughput, 4: Spectral Efficiency, 5: PEP , 6: PAPR, 7:Ergodic sum capacity
Notations- ✓: Y, and ×:N

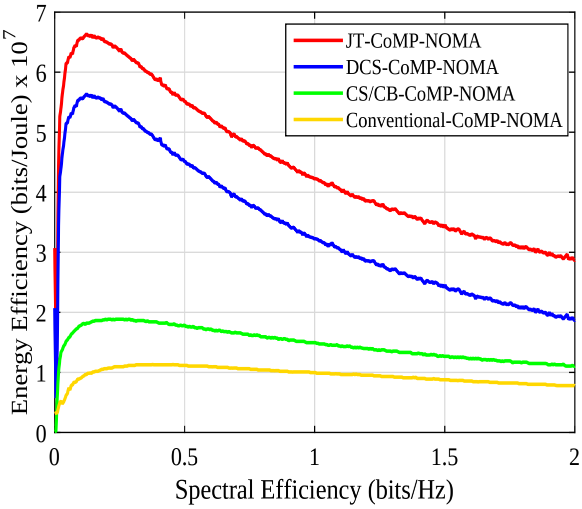

FIGURE 14: Comparison of various NOMA schemes on CoMP

and user fairness. Considering the aforementioned benefits, the authors have proposed different variants of FD-NOMA, which are discussed as follows:

1) JPCUA-FD-NOMA [105]

In this, authors investigated the coexistence of NOMA and FD to improve both SE and user fairness. Here, the SIC technique is applied at both the uplink and downlink transmissions. The authors formulated the problem of jointly optimizing user association (UA) and power control to maximize the overall SE for minimum data rate requirements and power constraints. Firstly, the authors used the continuous relaxation problem to overcome the inner convex approximation framework to address the problem. Next, to accelerate the performance of the framework, the authors used the penalty method. Also, to optimize UL users' decoding order and DL users' clustering, the tensor model was used. Simulated results showed that the proposed scheme outperformed the conventional FD-based schemes and their HD counterpart.

2) C-SWIPT-FD-NOMA [106]

In this scheme, the authors studied the NOMA with the cooperative spectrum-sharing network. Here, the FD and NOMA technique was integrated on the secondary transmitters (STs) to transmit data to the primary and secondary receivers. To analyze the network's performance, the authors derived the tight closed-form approximations of the outage probability and system throughput for both the primary and secondary networks. Also, the authors proposed the rapid convergent iterative algorithm to optimized the sum-rate and power allocation coefficients. Numerical results showed that the combination of FD, SWIPT, and NOMA techniques highly improved the performance of the cooperative spectrum-sharing network in terms of OP, throughput, and sum-rate in comparison to the HD-NOMA and TDMA.

3) BAHyNOMA [107]

In this, authors combined the NOMA and buffer-aided FD relay to enhanced the SE of a single-source two-user network. Here, the authors proposed the hybrid BA FD/HD NOMA relay selection algorithm named BAHyNOMA to improve the outage probability, average sum rate, and average delay.

Furthermore, to improve the end-to-end communication, an opportunistic relay selection technique was proposed, doubling the average sum rate and reducing the latency.

4) EC-FD-NOMA [108]

In this paper, the authors integrated the FD-NOMA technique over the edge caching scheme to improve the proximity services at the network edge. Here, the edge node (EN) transmitted the cached file to the user using a direct link and worked as an FD-mode relay to retrieve the un-cached file from its nearby ENs to forward the file using a relay link. During this process, NOMA is used to carry out both the direct and the relay transmission. The authors used the successful offloading probability (SOP) over the scalable power allocation technique to analyze this problem.

5) FD-C-NOMA [109]

In this paper, the authors integrated NOMA with an FD-cooperative scheme. Here, in the first phase, the BS transmits a new signal for the strong user, whereas, in the second phase, the weak user performed a SIC to obtain its signal. This scheme overcomes problems of pre-existing schemes where the BS and strong user perfectly resolved signals using the SIC and combined at the weak user. Numerical results demonstrated that the proposed scheme achieved a better sum rate as compared to the other schemes.

E. COGNITIVE RADIO

A CR network offers a dynamic spectrum allocation (DSA) technique to make efficient use of spectrum. The two important users in DSA are Primary users (PUs) and secondary users (SUs). PUs are the proprietor of a licensed channel and utilize the spectrum first. At the same time, SUs are opportunistic users whose function is to sense the licensed spectrum without creating interference for the PUs. Moreover, SUs identify the unused channels and keeps a watch on the locally available channel when PUs are absent [110]. Cognitive radio (CR) communications can be classified into three models: interweave, underlay and overlay. In the interweave model, SUs can use spectrum only if PUs are inactive; the activities of PUs are monitored continuously to avoid interference caused by the transmission of SUs. In the underlay model, SUs transmit with low power as compared to PUs. In the overlay models, codebooks and messages are used to identify the PUs, which reduces the interference. Description of the various CR based NOMA variants are as follow.

1) D-NOMA [111]

In this, the authors proposed a dynamic power allocation scheme, where power allocation coefficients are varied dynamically to the instantaneous channel gains. The scheme provides a guarantee to serve different (strong and weak) users' simultaneously. It avoids getting lesser date rates for weak channel condition users' in F-NOMA and strong channel condition users' in CR-NOMA. This scheme achieves similar diversity gains like F-NOMA and large diversity gain than CR-NOMA. The performance of D-NOMA is analyzed in terms of OP and average user rate. The authors evaluated the power allocation coefficient for both the DL and UL scenarios and proved that D-NOMA performs better than OMA, F-NOMA, and CR-NOMA. It is suitable for user pairing/clustering algorithm for a large-scale network and with the MIMO scenario when the condition of CSI for the transmitter is imperfect.

2) CR-NOMA-D-M and CR-NOMA-D-U [112]

It is a CR-inspired NOMA scheme that provides dynamic QoS for multicast, and unicast users [112]. In CR-NOMA-D-M, multicast users behave as PUs, and the rate of these users is greater than OMA, while in CR-NOMA-D-U, unicast users act as PUs. The power allocation coefficients of both these schemes are dependent upon the channel fading gains. The performance of both these schemes illustrated that they provide better results in terms of the diversity order and secrecy OP compared to CR-NOMA-F-M and OMA.

3) CR-NOMA-OFDM [113]

It consists of NOMA with cognitive OFDM systems, where the sensed spectrum is split into subcarriers, and the NOMA is applied on each subcarrier to give access to multiple users [113]. It maximizes the total weighted capacity of the system by jointly optimizing the sensing duration, user selection, and power allocation. The aforementioned problem is decomposed into three subproblems: (i) the optimal sensing duration is found by the bisection search method, (ii) matching theory is adopted to optimize user selection, and (iii) the difference of convex programming is utilized to obtain efficient power allocation on subcarriers. Finally, an alternate iteration algorithm is also used to derive a joint optimization and to boost SE.

4) MIMO-CR-NOMA [114]

The authors studied an outage-oriented joint AS algorithm for MIMO-CR-NOMA networks to maximize the SNR of SUs keeping given the QoS of PUs. The authors analyzed the asymptotic closed-form expression for OP and diversity to prove that their scheme performs better than the OMA scheme.

5) PFDM/SFDM [115]

In [115], the authors proposed a NOMA-based CR scheme, where SU access the multiple subchannels both at present and absence of PU. In this scheme, the SU can transmit the data directly in the subchannel while PU is absent and use NOMA to communicate when the PU is present. The PU first decoding method (PFDM) and the SU first decoding method (SFDM) was used at the receiver side to decode the NOMA signals. In the PFDM, the PU signal is first decoded and reconstructed, and then the SU signal is decoded by cancelling the PU signal from the received signal. Then, the PU throughput is decreased due to the interference caused by

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the SU, but the SU achieves perfect throughput. In the SFDM, the SU signal is first decoded and reconstructed, and then the PU signal is decoded by removing the SU signal from the received signal. The SU throughput can be decreased because of the interference brought by the PU, but the PU can achieve perfect throughput.

6) CSS-NOMA [115]

It is a 2-phase overlay cooperative spectrum sharing (CSS) protocol where NOMA is integrated with CRN to raise SE [116]. In this protocol, the PU uses the entire time slots and spectrum during the first phase without leasing them to the SU. On the other side, in the second phase, the SU, which coexists with the PU, allocates its power to forward the primary symbol and its transmission simultaneously, based on the NOMA approach. In this scheme, three data symbols can be transmitted during the two phases. The performance of this scheme was analyzed in terms of ESC and OP. It achieved a better performance than the TDF, CRS-NOMA, CRS-NOMA-ND, and SC-SS in E-SC, whereas OP depends upon the user target data rates and the power allocation coefficient.

7) MCR-NOMA [117]

It is a dynamic cooperative scheme, where the multicast SUs serve as relays and collaboratively retransmit the signals intended for the PUs and SUs, respectively. It can be directly applied to current cellular networks, where local SUs may have common packets for nearby receivers. It improves the reliability of secondary multicast transmissions if the signals for both networks are decoded correctly by the SUs. This cooperation is particularly preferred by the primary network when the primary network cannot meet the PU's QoS. In this scheme, three different user scheduling strategies were proposed based on available CSI: instantaneous CSI, partial CSI, and full CSI. It attained a significant performance gain and also achieved the spatial diversity order by opportunistically using the user scheduling strategy as per available CSI.

8) Reliability oriented secondary user scheduling and fairness oriented secondary user scheduling (R-SUS and F-SUS) [118]

The authors introduced the NOMA-based cooperative overlay spectrum sharing framework, which considered multiple SUs using multi-user diversity to cooperate between the primary and secondary networks. In this framework, the SUs act as the relays which forward the received signals to PUs using the NOMA protocol. To facilitate the NOMA-assisted cooperation, they consist of two SU scheduling schemes: R-SUS and F-SUS. The R-SUS scheme was used to minimize the optimal outage performance for both the PUs and SUs, whereas the F-SUS scheme provides an equal opportunity for all SUs for cooperation. For both the schemes, a closed-form expression of primary and secondary OPs was derived, and the network diversity order was investigated. The results demonstrated that both the proposed schemes have full diversity orders for PUs and SUs. But, F-SUS loses the OP of SUs in contrast to the R-SUS scheme.

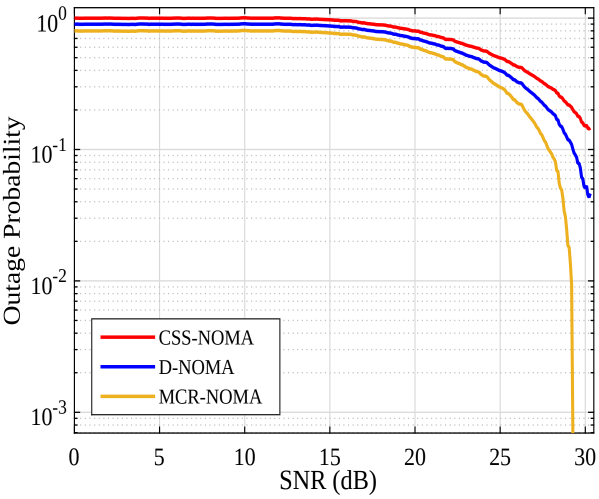

FIGURE 15: Comparison of various NOMA scheme for CR

9) Comparison of existing NOMA schemes based on cognitive radio

- Table 8 provides the detailed relative comparison of existing variants of NOMA used in cognitive radio concerning parameters such as transmission scenario, a technique used, merits, open issues, throughput, EE, capacity, and latency.
- Fig.15 shows the comparison between the outage probability and signal to noise ratio. The system model, parameters, and environment used in the simulation are taken from [111]. The result implies that MCR-NOMA achieves lower outage probability as compared to the D-NOMA and CSS-NOMA. This happened due to the following reasons: (i) it used round-robin scheduling to improve the diversity order (ii) it serves both the primary and secondary users simultaneously without consuming additional frequency resources. This indicates the worth of MCR-NOMA for CR in the 5G network.

F. MACHINE-TO-MACHINE

In machine-to-machine (M2M), machines can communicate and exchange information with each other with or without human intervention. The presence of an autonomous connection between the machines generated heterogeneous data traffic and imposed a huge amount of traffic in the form of small and frequent data on the UL [119]. In M2M, as per the type of machines and their applications, they require diverse service requirements. To handle the M2M communication in 5G, key challenges are as follows.

- *Control overhead:* In M2M, control overhead needs to be minimized because payload data generated by most of the M2M applications is small in size.

TABLE 8: Parametric analysis of existing NOMA schemes in CR

Problem in CR	**NOMA Variant**	**Transmission scenario**	**Techniques**	**Performance metrics**						**Merits**	**Open issues**
				1	**2**	**3**	**4**	**5**	**6**		
QoS of better channel condition is sacrificed	D-NOMA [111]	Downlink	Dynamic power allocation	✓	✓	×	×	×	×	Guaranteed to serve the users having weak channel condition and improves the QoS of users having better channel condition	User pairing /clustering algorithm in a large scale network and can be extended for MIMO with imperfect CSI at transmitter
Multicast-unicast traffic management in MISO-NOMA	CR-NOMA-D-U/CR-NOMA-D-M [112]	Downlink	Power allocation	×	✓	×	×	×	×	Higher data rates are achieved as compared to OMA schemes	Can be extended for MIMO-NOMA and the co-channel interference can be reduces when integrated with OMA schemes
Maximize the total weighted capacity	CR-NOMA-OFDM [113]	Downlink	Joint Bisection search method based sensing duration, matching theory-based user selection and DC programming based power allocation	×	×	×	×	✓	×	Boosts the system capacity of the accessible user	Sensing time can be increased.
Outage oriented antenna selection	MIMO-CR-NOMA [114]	Downlink	Subset based joint antenna selection	×	×	×	×	✓	×	Maximizes the SNR of SU keeping QoS of PU satisfied.	Can be extended to mMIMO.
SU can access the spectrum when PU is idle	PFDM/SFDM [115]	Downlink	Joint spectrum resource and subchannel transmission power allocation, and Sensing time selection	×	×	✓	×	×	×	Enlarges the throughput of PU and SU	Sensing time needs to be increases to improve the performance
Primary network performance	CSS-NOMA [116]	Downlink	Cooperative transmission scheme for CRN network	×	✓	✓	×	×	×	An improved win-win situation is achieved and spectrum was utilized efficiently.	FD mode can be used at nodes.
Cooperative transmission for multicast CR	MCR-NOMA [117]	Downlink	Dynamic cooperative and user scheduling schemes are used for spatial diversity	×	✓	×	×	×	×	Improves reception reliability and can access the spectrum simultaneously.	Can be extended to imperfect CSI.
Overlay spectrum sharing for multi-user CRN	R-SUS & F-SUS [118]	Downlink	Cooperative spectrum sharing and two user scheduling schemes (R-SUS & F-SUS) are used.	×	✓	×	×	×	×	R-SUS provides full diversity order, and F-SUS improves the user fairness.	Can be extended to imperfect CSI.

Note- 1: Average rate, 2: OP, 3: Throughput, 4: EE, 5: Capacity, and 6: Latency
Notations- ✓: Yes,and ×: No

- *Scalability:* The data traffic generated by devices is dynamic. Therefore, the network's capacity must be large so that the network can easily tolerate the changes in the node density with small information exchange.
- *Energy efficiency:* The devices used in M2M are battery operated and have a limited lifetime. To improve the EE of devices, the energy spent on radio access and data transmission need to be controlled.
- *Transmission latency:* To minimize the transmission latency in M2M, the channel access delay needs to be reduced.
- *Random access and resource allocation:* The numbers of radio resources available in 5G are limited. Therefore, an effective resource allocation scheme is required to control and exchange the messages. Proper management of resource allocation prevents co-channel interference.

To overcome the aforementioned challenges in M2M, researchers integrated NOMA with M2M communication and proposed different variants described as follows.

1) CS-NOMA [120]

It is an asynchronous CDMA uplink transmission scheme to enable joint detection of active users with their data [120]. In this scheme, a new version of the spreading technique called low spreading sequence (LCS) was introduced. For LCS signature, mutual coherence is non-zero but far less than 1, due to which the number of LCS signature exceeds the value of N, which results in a high system overload. In this proposal, CS-MUD is deployed in the BS to recover a sparse signal. The estimation of the sparse signal can be achieved by an orthogonal matching pursuit (OMP) algorithm. To analyze the recovery of sparse signal in the presence of noise, two conditions have been used: coherence property and restricted isometry property. Moreover, this variant with perfect CSI and imperfect CSI attains a high system overload when the active users are relatively sparse. It also enhanced the SE, mitigate the control overhead, and reduced the transmission latency.

2) EE-NOMA [121]

It is an energy minimization scheme for M2M communication in an UL scenario [121]. In this scheme, the authors assumed that the UE acts as a machine type communication gateway (MTCG) that can decode and forward information of machine type communication devices (MTCDs) and their data directly to the BS. Then, an efficient energy network for M2M communication can be achieved using MTCD and UE rate constraints. It consumes less energy as compared to the existing NOMA and TDMA schemes. Moreover, when the number of MTCDs increases and reaches up to 100, and then a 0.18 Joule amount of energy is consumed, which is lower than the traditional schemes.

3) Spatial group based random-non-orthogonal resource allocation access (SGRA-NORA) [122]

It consists of non-orthogonal resource allocation (NORA) with the spatial group based random access (SGRA) [122] to resolve two shortage problems of random access (RA) (i) Preamble collision (PA) problem which arises due to limited RA in preambles on physical RA channels (PRACH), and (ii) Congestion and overload problem which arises due to limited physical UL shared channel (PUSCH) resources. The aforementioned problems can be solved in three steps: (i) by using a large number of the preamble, (ii) non-orthogonally allocation of the same PUSCH resource blocks (RBs) to a group of machine nodes belonging to distinct spatial groups, and (iii) decoding of multiple received RA data by using SIC. It effectively utilizes both the PRACH and PUSCH and has a high RA success probability within a limited RBs allotted for M2M communication, and outperformed the conventional RA scheme.

4) NM-ALOHA [123]

The authors in this used the NOMA technique to multichannel ALOHA for the RA scheme, which effectively increases the number of subchannels by using multiple subchannels and power levels for RA. It provides a higher throughput as compared to multichannel ALOHA by using different power levels. Moreover, it improves the number of subchannels without expanding the bandwidth and reduces the transmission power because its transmission power was based on NOMA.

5) ALOHA-NOMA [124]

Pure ALOHA integrated with PD-NOMA was proposed to provide scalability, EE, and high throughput MAC protocol to handle the requirements of low complexity devices for IoT applications [124]. Moreover, the presence of the SIC receiver at the gateways reduced the retransmission of IoT devices and avoided the continuous listening of the channel. This happened because it is difficult to separate the multiple signals transmitted in the same frequency band at the same time interval. Then, the number of active IoT devices cannot be estimated due to their throughput degraded. A dynamic frame structure with robustness was proposed to overcome it, which calculates the number of active IoT devices transmitted in ALOHA using multi-hypothesis. It has less time for payload transmission and also protects the degradation in throughput. It outperformed pure ALOHA. When five active users are successfully separated via SIC, the throughput achieved by pure ALOHA was 0.18, while in ALOHA-NOMA, it was 1.27.

The author in [125] proposed an uncoordinated random access protocol for the enhancement of ALOHA-NOMA which provides an IoT gateway to determine the number of active IoT devices following are the advantages of this scheme (i) easy estimation of the SIC power levels, and (ii) signals transmitted by different IoT devices in the same time and frequency can be easily separated. It has a throughput gain of 5.5dB over conventional slotted ALOHA.

6) RNOMA [126]

It was based on grant-free property and used to solve two problems of mMTC (i) massive connectivity and (ii) signalling overhead. Each user randomly transmits the same packet on each RU as per their optimized probability in this technique. Moreover, the interference at the receiver can be removed by using intra and inter-RU SIC. It performed better than slotted ALOHA in terms of reduced signalling overhead.

7) GRANT-FREE NOMA [127]–[138]

In human-to-human (H2H) communications, devices are lesser in numbers, but they generate data with high data rates and large packet sizes [127]. In contrast to H2H, transmission and arrival of data packets in mMTC are smaller in sizes [129]. In this technique, controlling the signal overhead and accessing the channel are the major issues of mMTC. Generally, in grant-based transmission, users require four-step random access (RA) procedure to access the channel. In the case of mMTC, it is impossible to establish a dedicated connection for the data transmission because signalling overheads for coordination are proportional to the number of devices. Therefore, a grant-free transmission is a viable solution for mMTC.

In grant-free transmission, devices directly communicate with each other without depending upon the BS permission [130], the devices can transmit data in a UL scenario in an arrive-and-go manner [130], [131]. However, the contention is the main problem that needs to be resolved because multiple users transmit using the same channel and at the same time. The authors in [132], [133] proposed two grant-free techniques. The first one is based on mMIMO, and the second is based on NOMA principle [134]. In the first technique, the spatial degree of freedoms was exploited, while in the second, the MUD techniques were explored.

Integration of NOMA with grant-free transmission results in low latency, low signalling overhead, fewer devices cost, and reduced device energy consumption. The authors in [135] applied a PD-NOMA with grant-free to increase the number of connections by assuming that the BS knows the CSI of both the transmitter and receivers to

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achieve an optimal subchannel and power allocation. But, these techniques are not suitable for grant-free due to large signalling overhead. This issue was addressed by [136], [137] which integrates the CD-NOMA with grant-free, where a compressive sensing technique for MUD was used. But, the requirement of user's prior information makes the design and computational complexity of the receiver two challenging problems.

Jiang *et al.* [138] proposed a distributed NOMA, power MA, grant-free NOMA framework with a hybrid transmission scheme to mitigate the problems of a high collision probability that arises due to grant-free random access. It also reduces the number of MTCDs by dividing the cell into different layers based on different power levels. Moreover, to improve the throughput, they proposed an Enhanced Access Barring (EAB) mechanism to control the congestion and reduce overhead. To reduce the receiver-side computational complexity, the author used MUD based on the different power levels of devices. The authors in [128] proposed a technique to resolve the issue for an increase in the number of admitted users for grant-free access.

8) Comparison of existing NOMA schemes based on M2M

- Table 9 provides the detailed relative comparison of existing variants of NOMA used in M2M communication using parameters such as the transmission scenario, technique used, merits, throughput, EE, sum rate, and latency.
- Fig. 16 represent the variation in network throughput to the number of devices. The system model, parameters, and environment used in the simulation are taken from [124]. The graph implies that when devices in the network are less in number, then the throughput is high, but as the number of devices increases continuously, the throughput starts decreasing. Moreover, the comparison shows that R-NOMA performs better than the three schemes named ALOHA-NOMA, CSS-NOMA, and SGRA-NOMA. It utilizes the grant-free NOMA scheme, which reduced the interference among the devices, resulting in a decrease in signaling overhead.

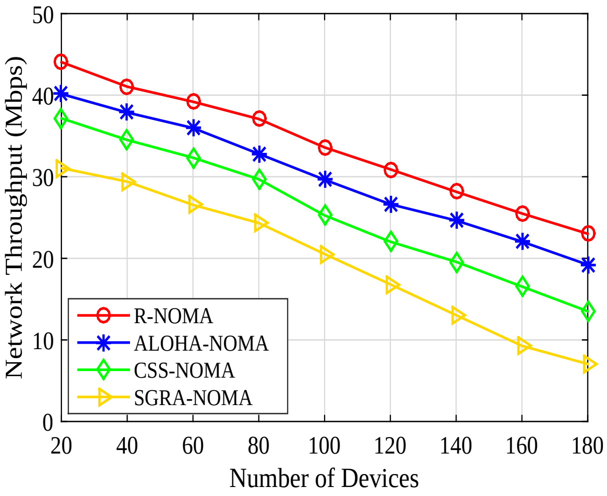

FIGURE 16: Comparison of various NOMA schemes on M2M Communication

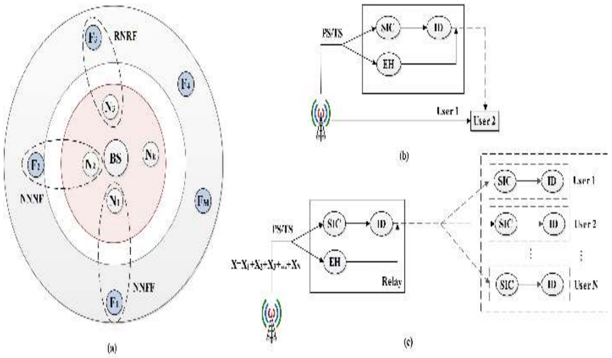

FIGURE 17: Block diagram of SWIPT

G. SWIPT AND WPCN

Apart from improving SE, EE is another critical issue that needs to be addressed in the 5G wireless network. Generally, most of the devices used for communication are equipped with batteries with a limited lifetime, as shown in Fig. 17. So, to prolong the lifetime of these energy-constrained devices, energy harvesting (EH) is an effective technique. Initially, EH techniques harvest the energy from renewable resources such as sunlight, wind, but these techniques are not reliable as they depend upon the environment. In contrast to this, SWIPT emerges as the popular EH technique, where nodes or terminals harvest the energy from electromagnetic radiation of RF signals during data decoding. It harvests the energy even from the interfering signals. C-NOMA observed that when strong users acted as a relay for weak users, their batteries drained fast. So, the signal strength of both the strong and weak users degraded. This problem motivates both academia and industry researchers to use SWIPT with C-NOMA to enhance network EE as follows.

1) C-SWIPT-NOMA [139]–[143]

The combination of SWIPT with NOMA was first explored in [139], in which users were randomly located. In this technique, strong users at the time of relaying harvest the energy from RF signals of the BS and then forward the data to the weak users. In [141], the authors designed a transceiver for C-NOMA, where multiple antennas were used with the BS and a single antenna with other users. To maximize the rate of relays, the authors in [141] designed joint transmitter beamforming, power splitter, and receiver filter scheme with the QoS constraint of weak users and power constraint of the BS, respectively. Moreover, a zero-forcing (ZF) beamforming design was developed at the transmitter side. These two schemes outperformed the direct transmission scheme.

In contrast to [139], the authors in [142] investigated the impact of user association. In this technique, the authors pro-

TABLE 9: Relative comparison of existing NOMA schemes based on M2M communication

Problem in M2M	NOMA variants	Transmission scenario	Techniques	Performance metrics							Merits
				1	2	3	4	5	6	7	
Latency and overhead	CS-NOMA [120]	Uplink	LCS and OMP algorithm	×	×	×	×	✓	×	×	Improve the SE and avoid the control signaling overhead and reduce the transmission latency.
Energy efficiency	EE-NOMA [121]	Uplink	Time scheduling and power control	×	×	×	✓	×	×	×	Energy reduced upto 0.18J for 100 MTCDs less than the conventional schemes
PA and PUSCH shortage problem	SGRA-NOMA [122]	Uplink	Resource allocation	×	✓	×	×	×	×	×	RA success probability reaches upto 90% with 30 RBs, which is significantly higher than 30% of the conventional RA scheme
Latency	ALOHA-NOMA [124]	Uplink	dynamic frame structure	×	×	✓	×	×	×	×	Enhances the throughput and minimizes the retransmissions of IoT devices
Signalling overhead	R-NOMA [126]	Uplink	Power control and frame structure	×	×	✓	×	×	×	×	Grant-free property of NOMA reduced the signalling overhead

Note- 1: Sum rate, 2: RA Success Probability, 3: Throughput, 4: EE, 5: Latency, 6:PAPR, and 7:Ergodic sum capacity.
Notations- ✓: Yes, and ×:No

posed three types of users' selection schemes (RNRF, NNNF, and NNFF) based on the euclidean distance from the BS. It has lower OP and higher system throughput as compared to the random selection users scheme. Moreover, the presence of the SWIPT technique reduced the effect of low diversity gain compared to conventional NOMA. Similar to [142], the authors in [143] proposed a best near and best far (BNBF) user selection scheme which achieved a diversity order of $M + 1$ without being dependent upon the number of the nearest users. In this technique, M represents the number of farthest users. In [140], the authors explored the performance of C-SWIPT-NOMA having a BS and two users. Users near the BS act as relays having multiple antennas, while the user farthest from the BS had only a single antenna. Moreover, they used beamforming and random selection strategies to analyze the performance of their scheme in terms of OP to have better results compared to the other two schemes.

2) C-SWIPT-MISO/SISO-NOMA [144], [145]

In [144], the authors implemented the TAS scheme with MISO-NOMA used with the hybrid SWIPT protocol. They divided the TAS scheme into two criteria: criterion-I and criterion-II. In both these criteria, they selected an antenna that provides a channel having the best fading condition from the source to the farthest users and the nearest users, respectively. Hybrid SWIPT was used with the nearest users to power the relaying operation. Still, for the farthest users, criterion-I and criterion-II achieved a diversity order of $K+1$ and 2. In contrast, for the nearest users, it becomes 1 and K, where K represents the number of transmit antennas at the BS. In contrast, to [144], the authors in [145] implemented the C-SWIPT-NOMA transmission strategy with MISO and SISO techniques. First of all, a power splitting technique was used at the EH relays. Using it, the relays forward the information by harvesting the energy from the RF signals only and protecting their battery's consumption. Second, the MISO technique was studied to maximize the data rate of strong users. To achieve the target, the authors first proposed the semi-definite relaxation (SDR) technique to reduce the quadratic terms related to the beamformers. They applied the exhaustive search to achieve the optimal global solution. Moreover, to reduce the high complexity of the exhaustive search, the SCA-based iterative algorithm was proposed to obtain the stationary point. Third, the SISO technique was used in the transmission strategy to study practical applications. It outperformed the existing schemes and maximized the data rate of strong users with the condition to provide guaranteed QoS to weak users.

3) NOMA-EH [146], [147]

Similar to C-SWIPT-NOMA, the authors in [146], [147] combined SWIPT with NOMA, where relay nodes (strong users) were equipped with EH techniques that provide communication between the BS and multiple users. In this technique, multiple antennas were used at both the BS and users' sides. Moreover, transmitting antenna selection (TAS) and maximal ratio combining (MRC) techniques were also used at the BS and multiple users. Performances of these schemes were analyzed in terms of a closed-form expression of outage over Rayleigh and Nakagami-m fading channel distribution, respectively. It outperformed the SE and user fairness as compared to OMA-EH.

4) SWIPT-F/CR-NOMA [148]

In this, the authors explored the impact of two types of power allocation schemes in C-SWIPT-NOMA. The first scheme was based on fixed power and the second on CR. From source to relay Nakagami-m and from the relay to users, Rayleigh fading distribution was used in this scheme. In SWIPT-F-NOMA, users' power allocation coefficients were fixed, and more power was allocated to the weak users compared to strong users. On the other hand, in SWIPT-CR-NOMA, power allocation coefficients were opportunistic. It provides different trade-offs among user fairness, reception reliability, and system complexity. Both the proposed schemes lower the OP but achieved the same diversity gain as compared to SWIPT-OMA.

5) SWIPT-NOMA-HETNET [149], [150]

In these authors proposed an energy-efficient resource allocation scheme for simultaneous wireless information and power transfer (SWIPT)-Non-orthogonal multiple access (NOMA) based femtocells users with imperfect channel state informa-

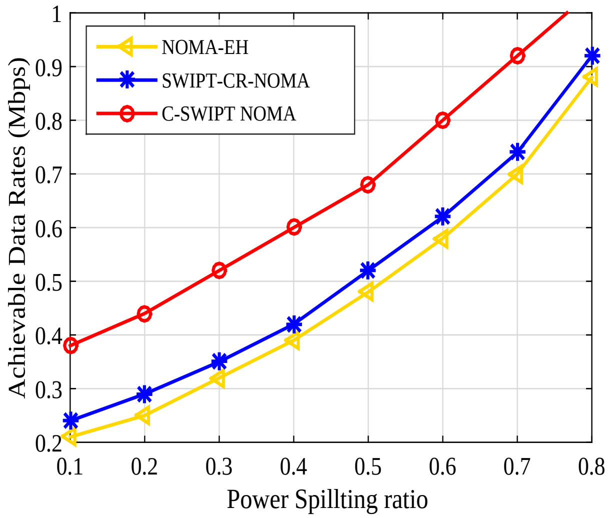

FIGURE 18: Comparison of various NOMA schemes on SWIPT-NOMA

tion. A dynamic resource allocation scheme by using SWIPT and NOMA with femtocells is investigated. Energy efficiency is calculated with the help of the Dinkelbach technique. Also, the many-to-many matching technique is used to develop the subchannel allocation. The preference list of macro-users and Femto-users has been developed based on their harvested energy from the MBS and FBS radio frequency signals. To optimize the power of FBs, SCALE is applied to convert the non-convex problem into convex. The optimal value of power is calculated by using the dual Lagrangian decomposition method with KKT conditions.

6) WPCN-NOMA [151]–[153]

In the WPCN model, the users transmit the data signals towards the BS and harvest the energy from the signals to charge their batteries. But, on the other side, the receivers cannot transmit the data along with energy harvesting. To overcome it, the authors in [151] used the WPCN with NOMA in a UL scenario having one BS and multiple EH users. In this technique, the users harvest the energy from the BS by using the harvest-then-transmit protocol scheme. The authors in [151] proposed two types of decoding strategies to improve users' data rates and provide fairness among them. It provides an improvement in EE, user fairness, and throughput as compared to TDMA. In contrast, to [151], the authors in [153] proposed a joint time allocation (uplink), energy beamforming, and receiver beamforming (downlink). It outperformed fixed power allocation and OMA schemes. In [152], the authors proposed a resource allocation scheme to mitigate the doubly near-far effect. They also proposed joint power allocation with the duration of energy harvested and information transmission. Compared to TDMA, it achieved a higher rate for CEUs with better fairness.

7) Comparison of NOMA schemes based on SWIPT and WPCN

- Fig. 18 shows the variation in the rate of energy harvesting for the power splitting ratio. The system model, parameters, and environment used in the simulation are chosen from [139]. The graph implies that C-SWIPT-CNOMA provides better performance as compared to SWIPT-CR-NOMA and NOMA-EH. In C-SWIPT-NOMA, the pairing schemes among the users were performed based on their Euclidean distance from the BS. The authors in [142] investigated the pairing schemes more efficiently and proposed the following: (1) random near and random far user (RNRF), in which pairing was assigned randomly; (2) nearest near and nearest far user (NNNF), in which the nearest near and far users to the BS were paired; and (3) nearest near the user and farthest far user (NNFF), in which a near user that is closest to the BS is paired with a far user that is farthest from the BS. The best pairing strategy is NNNF, as it minimizes the outage probability and maximizes the achievable rates for both near and far users. Also, by choosing transmission rates and power splitting coefficients carefully, one can achieve guaranteed performance results without using the near users' energy to power the relay phase transmission. This shows that C-SWIPT-NOMA is more suitable for SWIPT under the 5G Scenario.

H. BACKSCATTER COMMUNICATION

Backscatter communication (BackCom) is a promising technique for low-energy communication systems [154]. For the BackCom system, the passive/semi-passive backscatter nodes (BNs) can not only reflect and modulate the signal but also implement EH to support its operation [154]. The power consumption for a low power BN is generally matched with the harvestable wireless energy from an RF source [154]. Thus, BackCom can greatly save energy for low-power devices. The architecture of BackCom is classified into three types [154]: (i) monostatic BackCom (ii) bistatic BackCom (iii) ambient BackCom. The major drawbacks of BackCom are (i) doubly near-far problem, i.e., the signal experiences a round-trip path-loss (ii) higher energy outage probability (iii) lower modulated backscatter signal strength (iv) generate direct interference to backscatter receivers (v) ambient RF sources of ambient backscatter communications systems are not controllable. To overcome these issues, researchers from both academia and industry integrated NOMA with BackCom. Some of the variants of NOMA with BackCom are as follows.

1) BAC-NOMA [155]

In this, authors proposed an effective spectrum and energy cooperation among uplink and downlink transmission. The paper's main aim is to maximize uplink throughput while reducing the interference between downlink and uplink transmission. The numerical results claimed that the BAC-

NOMA obtained superior performance as compared to the conventional schemes. This scheme is found to be suitable for mMTC communication.

2) BC-NOMA [156]

In this paper, NOMA is integrated with backscatter cooperation (BC). This scheme aims to backscatter the surplus power of the received downlink signals at one user to enhance the reception of the user who cannot recover its information. To evaluate the performance of the proposed scheme, three schemes are used: non-cooperation (NC)-NOMA scheme, the conventional relaying (CR)-NOMA scheme, and the incremental relaying (IR)-NOMA scheme. The outage performance, the expected rate, and the diversity-multiplexing trade-off (DMT) performance are analyzed for all these schemes. The results showed that the proposed scheme enhances transmission reliability as compared to the NC-NOMA.

3) BBCN-NOMA [157]

This scheme studied the problem of resource allocation (RA) in a NOMA-enhanced bistatic backscatter communication network (BBCN). Here, time allocation and power reflection coefficients are jointly optimized to maximize the minimum throughput among all backscatter devices (BDs) while ensuring sufficient EH and SINR for NOMA decoding. To find the sub-optimal solution, the authors used the block coordinated proper and successive convex optimization techniques.

4) RA-NOMA [158]

In this, authors investigated the EE-based RA problem for a NOMA-BackComNet with guaranteed QoS. The authors formulated the EE-based maximization optimization problem of NOMA users by jointly optimizing the transmit power of the BS and RC of the BD and proposed a Dinkelbach-type RA algorithm to achieve the optimal solution and the maximum EE. Simulation results demonstrated the superiority of the proposed scheme is compared to the benchmark schemes.

5) Cognitive-NOMA [159]

In this paper, the authors investigated a multi-BD cognitive network with a backscatter system. Here, the authors used the multi-slot energy causality constraint to jointly optimize the primary user transmit power and the BDs reflection coefficients to maximize the sum rate. Besides, the authors have studied the performance of both the multi-slot operation and the single-slot operation under perfect SIC and imperfect SIC, respectively.

6) Hybrid-NOMA [160]

In this paper, the authors studied a hybrid TDMA-based PD-NOMA multiplexing scheme to increase the SE for field-deployed IoT sensors. The authors evaluated the performance of the BackCom-aided IoT network in terms of OP and network throughput. The simulation results showed that the proposed PD-NOMA scheme outperformed the conventional TDMA scheme to increase network capacity.

I. MIMO

In MIMO, multiple antennas are used at both the transmitter and receiver sides. It plays a vital role in 5G wireless communication due to the following reasons: (i) enlarge the coverage area, (ii) minimize the errors that arise due to multipath fading, (iii) provide high data rate, (iv) reduce bit error rate performance, (v) improved QoS for CEUs, and (vi) lower the outage probability. However, inter-user, inter-cluster, and intra-user interference are the major issues that need to be addressed in MIMO due to the matrix form of channels. These interferences in MIMO reduce the network SE and degrades the QoS of CEUs. NOMA is integrated with MIMO to resolve these issues, but in NOMA user requires special attention to power allocation and channel ordering. Hence, an efficient antenna selection and beamforming technique is required in the NOMA-based MIMO system to resolve this issue.

1) Antenna selection based MIMO-NOMA

Antenna selection is a technique that plays a key role in maintaining the diversity of the MIMO system [161] to reduce the adverse effects such as cost, complexity, and power consumption generated due to the usage of multiple antennas simultaneously. Researchers used the MIMO technique in the OMA system but cannot achieve a remarkable gain compared to MIMO-NOMA due to inter-user interference. So, to overcome this problem, the following variants are proposed.

a: TAS-NOMA [162]–[164]

It is a transmit antenna selection based scheme [162], in which the authors investigated the performance of the MISO-NOMA system in a DL scenario. In this scheme, multi-antenna is used at the BS side and a single antenna at each mobile user's side as shown in Fig. 19. In TAS-NOMA, an antenna having the highest SINR at the BS side was selected, whereas, in TAS-NOMA, an antenna that provides the maximum sum rate was selected. Moreover, the authors in [163] proposed a user scheduling algorithm for the mMIMO-NOMA system. In contrast to [162], the authors also analyzed the sum rate. In this scheme, the authors proposed an algorithm for two cases, single-band two users and multi-band multi-users. A search algorithm was proposed to search antennas that provide the highest channel gains in the first case. In the second case, a joint user and antenna selection algorithm was proposed to compute the normalized value of the desired antenna user-pair channel gain. The pair having the highest channel gain was selected. This scheme not only improves the system performance but also reduces the system complexity. The authors concluded that the TAS-NOMA scheme provides better performance than the OMA-based user and antenna selection schemes. However, the authors in [162], and [163] did not explore the system performance analytically, which was resolved in [164].

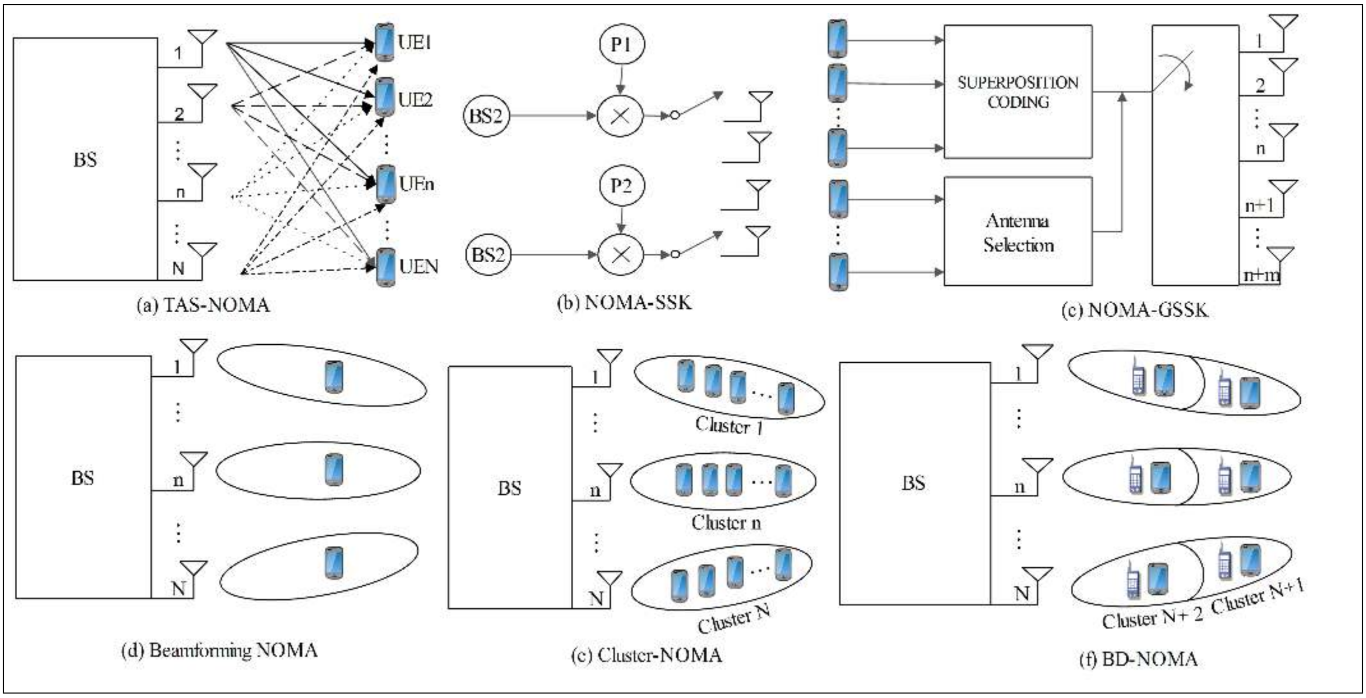

FIGURE 19: Block diagram of MIMO-NOMA: (a) TAS-NOMA, (b) NOMA-SSK, (c) NOMA-GSSK, (d) Beamforming NOMA, (e) Cluster-NOMA, and (f) BD-NOMA

b: AIA-AS/A^3-AS [164]

In this, the max-min-max and the max-max-max algorithms were proposed for the two users NOMA system. The max-min-max algorithm was used to improve the instantaneous channel gain of weak channel condition users, while max-max-max was used for strong channel condition users. The author applied this scheme to a model in which multiple antenna was equipped with both the BS and mobile users. They evaluated the asymptotic closed-form expressions for both the algorithms and also analyzed its average sum rate. The numerical results show that the max-min-max algorithm has better fairness and the max-max-max algorithm has a larger sum rate than the pre-existing schemes.

c: NOMA-SSK [165], [166]

It is a technique that is used to improve the SE of CEUs by combining NOMA with space shift keying (SSK) [165]. It is a type of MIMO technique that transmits information using the antenna index as compared to traditional modulation schemes [166]. The major advantages of SSK are that it reduces the receiver complexity and transmitter overhead. On the other hand, it has been observed that the number of transmit antennas used in SSK must be a power of two due to its characteristics, which is its major limitation.

d: NOMA-GSSK [167]

This technique overcomes the limitation on the number of transmits antennas of NOMA-SSK. To enhance the SE of CEUs, the authors in [167] proposed NOMA-GSSK. In this proposal, multiple transmit antennas are used, unlike NOMA-SSK. In this scheme, both power and spatial domains multiplex the users since it provides high SE, high EE, and low BER compared to NOMA-SSK and MIMO-NOMA. In addition to these features, this scheme also reduces the complexity of the system by reducing the number of SIC steps.

e: PD-NOMA-SSK [168]

In this, the authors proposed a scheme for group communication. To carry out group communication, the number of resources available for users is limited due to the different power level requirements of users through the PD-NOMA system. As a result, cryptographic keys cannot be distributed efficiently among users. The authors in [168] integrated the SSK modulation scheme with PD-NOMA to fulfill the demand for high SE by analyzing this problem. Also, to enhance the system throughput, the authors multiplex PD-NOMA-SSK with MU-MIMO techniques. The numerical results proved that the proposed PD-NOMA-SSK and PD-NOMA-SSK with MIMO enhanced SE by two to three times compared to the conventional NOMA and NOMA with MIMO techniques.

f: NOMA-HARQ [169]

In this, the authors investigate the HARQ design for downlink NOMA with single user-MIMO (SU-MIMO). The authors proposed this scheme to avoid inter-stream and inter-user interference. To handle the retransmission issue in MIMO-

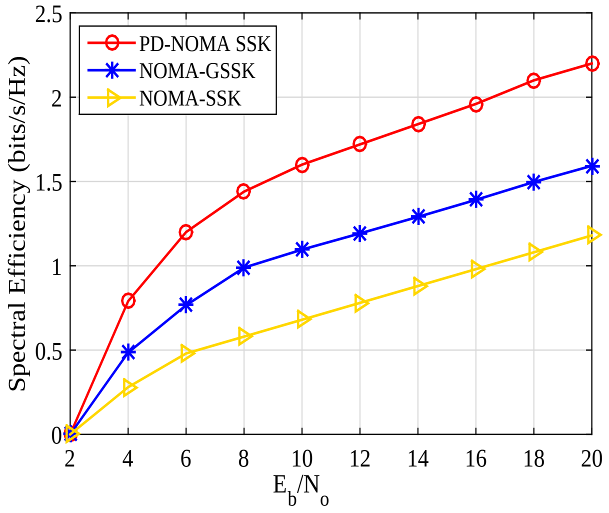

FIGURE 20: Comparison of various NOMA schems for Antenna Selection based MIMO

NOMA systems, the authors studied the impact of user pairing, precoding matrix adaptation, and transmission power assignment (TPA) ratio adaptation. The results showed that the HARQ probability of NOMA is much higher than OFDMA, and flexible retransmission strategies could increase performance gain. Moreover, the authors also proposed an enhanced HARQ algorithm, where opportunistic HARQ combined with the TPA scheme to achieve higher performance gain than the existing algorithm.

g: Comparison of various NOMA schems for Antenna Selection based MIMO

Fig. 20 shows the variation in spectral efficiency with respect to the E_b/N_o. The system model, parameters, and environment used in the simulation are taken from [167]. The graph implies that PD-NOMA-SSK achieves better spectral efficiency than the GSSK and SSK because, in PD-NOMA-SSK, a spatial domain technique was integrated along with PD-NOMA and SSK modulation. This combination increases the system spectral efficiency up to three times by using MIMO technology. Also, to mitigate the near-far effect, a user-grouping strategy was used, which improves the throughput 20% higher than the GSSK and SSK. This comparison shows that PD-NOMA-SSK is suitable for MIMO in the 5G network.

2) Beam-forming based MIMO-NOMA

Multicast beamforming is a technique used in MIMO-NOMA to enhance the sum capacity of the system, especially for the case of multi-users. It can be classified as single and multi-beams. In a single beam, a common single beam is allocated to all users in a group while, in multi-beams, different beams are applied to each group of users [170], [171].

a: NOMA-BF [172], [173]

In this, the authors studied the beamforming technique for the multi-user MIMO-NOMA system in a downlink scenario. In this scheme, the same beam is shared by a pair of users with different channel conditions. The authors proposed the user clustering and power allocation algorithm to reduce the inter-cluster and inter-user interferences. This scheme maximizes the sum capacity of the system. In contrast, to [172], the authors in [173] studied the usage of multicast beamforming in the MISO-NOMA system for two users. The transmitter of the BS is equipped with a multi-antenna which broadcasts the information using the multi-resolution technique. In this technique, the low priority signal is forwarded to the weak users (poor channel quality) whereas, both high and low priority signals are transferred to the strong users near the BS. In this scheme, the authors integrated a minimum power beamforming technique with SC to resolve power allocation and beamforming vectors for both the users. Moreover, a closed-form expression for optimal power allocation is also elaborated.

b: Random-BF-NOMA [174]

The authors studied the use of the random beamforming technique at the BS side. In this scheme, a single beam with the same power allocation coefficient is allocated to each user in a cluster. To mitigate the inter-cluster and inter-beam interference in a MIMO-NOMA system, the authors in [174] proposed a spatial filter. In addition to this, the authors also applied the concept of fractional frequency reuse (FFR) to improve the power allocation among multiple beams.

c: ZFBF-NOMA [175]

The authors in this applied zero-forcing beamforming (ZFBF) technique for multi-user MIMO-NOMA system in a downlink scenario. This technique mitigates inter-cluster interference, especially when the users have different channel conditions. In [175], the authors proposed a dynamic power allocation and user clustering algorithm to mitigate the interference and achieve the maximum throughput. The paper aimed to maximize system capacity.

d: Robust-BF-NOMA [176]–[178]

It was observed that most of the researchers have worked on the beamforming design of NOMA when the BS knows the perfect CSI of the users. However, it is difficult for the BS to know the perfect CSI of the users due to channel estimation and quantization errors in practice. So, to resolve the problem of norm-bound channel uncertainties, a robust beamforming technique based on the worst-case optimization framework was studied in [176]. They studied the robust beamforming in the downlink multiuser-MISO-NOMA system. In this scheme, a single beamformer was used for all users located in the same cluster.

In contrast to [176], the authors in [178], optimized the power of the beamformer while maintaining the data rate of each user. In this scheme, the signal for each user was

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transmitted with a dedicated beam-former. Differing from [176] and [178], the authors in [177] studied the robust beamforming technique in the MIMO-NOMA system using the cutting set method.

e: Coordinated beamforming NOMA (C-BF-NOMA) [179]

In [179], the authors investigated the problem of inter-cell interference in a multi-cell MIMO-NOMA based system. The authors proposed two algorithms: interference channel alignment CBF (ICA-CBF) and interference alignment CBF (IA-CBF) algorithms. In these schemes, two BSs mutually coordinate with each other in terms of their beamforming vectors to improve the QoS of CEUs without sharing the data between cells. Both these algorithms eliminate the intercell and inter-cluster interference, whereas the SIC technique of NOMA mitigates the intra-cluster interference. The first algorithm uses full CSI at the BS, while the second uses channel gains of CEUs. The numerical results show that both these algorithms performed better than traditional NOMA and OMA. These schemes improved the throughput and increased the number of served users.

f: BD-NOMA [180]

The authors observed that BDMA and NOMA could not directly be combined in the case of long-term feedback-based beamforming due to the problem of short-term channel variation. To resolve this issue, the authors in [180] used short-term feedback with the FDD-MU-MIMO system, which had multiple channel indicators (CQIs). For this, NOMA with BDMA can be used, which is known as BD-NOMA. In BD-NOMA, distinctive power is allocated to near and far users over each beam to mitigate the inter-beam and intra-beam interference at the same time. Moreover, the authors also proposed a weighted minimum mean square error (MMSE) based algorithm to solve the joint user selection and power allocation problem for BD-NOMA. The numerical results show that BD-NOMA for low interbeat interference (IBI) achieved a 20% WSR gain over BDMA when equal power is allocated over each beam. In contrast, the proposed scheme shows that BD-NOMA for high IBI achieved 10% WSR gain over BDMA.

g: VP-NOMA [181]

This is a hybrid NOMA transmission scheme designed for the MU-MISO system [181]. The basic idea behind this scheme was to minimize the total transmit power by using the beamforming matrix and power allocation technique. To minimize the transmit power, the authors designed a low-complexity greedy iteration algorithm to generate beamforming vectors. The numerical results showed that the vector-perturbation (VP)-NOMA reduces the transmit power compared to NVP-systems.

h: NOMA-MRT [182]

In this, the authors investigated the design of the adaptive transmission mode that switching between MMSE-BF and NOMA-MRT to maintain the achievable rate. The objective of the scheme was to achieve the maximum weighted sum rate for MISO downlink systems. Also, the authors proposed that when the channel vectors of the two users are highly correlated and perfectly aligned with each other, and MMSE-BF achieved an almost equal rate like NOMA-MRT. On the other hand, when two channels are orthogonal, MMSE-BF outperformed the NOMA-MRT.

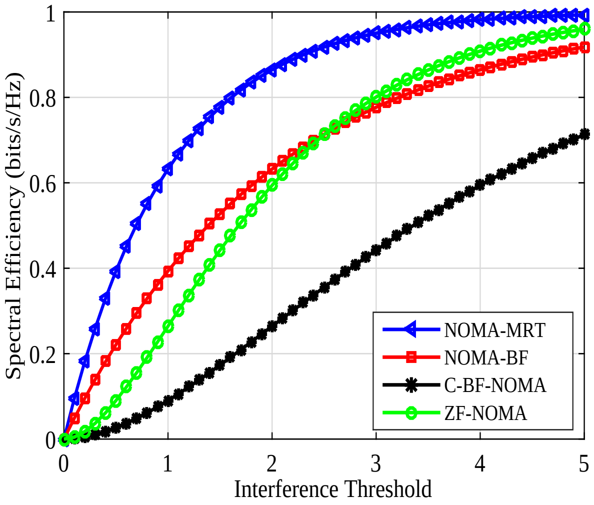

FIGURE 21: Comparison of various NOMA schemes for Beamforming MIMO

i: Comparison of various NOMA schemes for Beamforming MIMO

Fig. 21 represents the comparison between the outage probability and SNR. The system model, parameters, and environment used in the simulation are taken from [182]. The graph shows that C-BF-NOMA is suitable for 5G networks where massive high connectivity and low outage probability are required. This scheme perfectly deals with the inter-cell interference and increases the cell-edge users' throughput, which improves user fairness. In addition, as the number of users in a network increases, this scheme performs better than the others as this SIC and interference alignment technique is used to cancel the intra-cluster interference and inter-cluster interference, respectively.

3) Cluster based MIMO-NOMA

In this scheme, the users are partitioned into several different clusters, the appropriate beams related to the corresponding clusters are designed. Cluster-based MIMO-NOMA (CB-MIMO-NOMA) effectively suppresses the inter-cluster interference through an appropriate transmit precoder and detector. This technique ensured that the beam related to the particular cluster should be orthogonal to the users in other clusters. Due to cluster isolation, the difference between the users' channel conditions also increases. With this, the intra-cluster interference can also be mitigated from the SIC

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technique of NOMA.

a: NOMA-SM [183]

SM is energy-efficient MIMO techniques in which both amplitude-phase modulation and an index of transmit antennas are used to transmit the information bits. It was found that when OMA integrated with SM, low SE was achieved, while when transmit antenna grouping (TAG) integrates with SM, severe interuser interference was obtained. To overcome these problems, the authors in [183] integrate NOMA with SM in a downlink MU-MIMO scenario. With this scheme, the inter-user interference can be eliminated by deploying the SIC technique on the user's side. Moreover, to achieve high SE, the authors in [183] proposed a low complex power allocation scheme based on symbol rate error analysis. The authors also proposed the user pairing scheme to address the near-far effect. The numerical results show that NOMA-SM achieved better results than OMA-SM and TAG-SM.

b: SA-NOMA [184]

It is a technique used in the MIMO-NOMA system to eliminate inter-cluster interference. The authors in [184] applied this technique in a single cell framework to study the outage performance of both uplink and downlink MIMO-NOMA transmissions. In this scheme, stochastic geometry was used to study the impact of users' random locations and interferers. Moreover, the authors proposed two power allocation schemes to provide better trade-offs between users' fairness and throughput. The fixed power allocation (FPA) technique was used to have different QoS requirements, while the CR-inspired power allocation technique assures that users' QoS requirements must be fulfilled instantaneously. In [184], the authors also combined the SA-NOMA technique with the users' precoding selection scheme to exploit the spatial degree of freedoms of MIMO systems fully.

c: H-NOMA [185]

It is a precoding algorithm having low complexity as compared to DPC and ZFBF. It is based on the quasi degradation concept and is suitable for practical scenarios. The application of this algorithm was studied in [185] with the sequential user pairing technique for the two-user MISO-NOMA system. It optimizes QoS for two users and minimizes the transmit power having bound on data rates. The authors numerically and analytically analyzed the performance of H-NOMA using average transmit power and outage probability. The results show that H-NOMA outperformed both DPC and ZFBF.

d: PH-NOMA (Projection Hybrid-NOMA) [186]

It is an algorithm that combines Hybrid NOMA (H-NOMA) precoding and conventional ZFBF algorithm and was proposed to mitigate inter and intracluster interference for the multi-user MISO-NOMA system [186]. Moreover, to reduce overall interference and achieve low complexity, PH-NOMA with projection-based pairing algorithm (PBPA) and inversion-based pairing algorithm (IBPA) are combined using the properties of quasi-degradation. The performance of these algorithms was analyzed in terms of outage probability and diversity gain. To analyze the efficiency of these proposed BF algorithms, various performance evaluations are performed.

e: QR-NOMA [187]

The authors investigated the outage performance by using the precoding matrix and power allocation scheme. In this scheme, one transmitter sent information to two users, where one user received data (small packet) at a low rate and the other at a higher rate. The presence of a precoding matrix in this scheme reduces the user's effective channel gain but improves the signal strength of the second user. With this scheme, the potential of NOMA can be gained even when the participating users have similar channel conditions.

f: SBD-NOMA [188]

The authors in this proposed a scheme for an uplink MIMO-NOMA system with a fixed set of power allocation coefficients. It is a hybrid, multiple access schemes that inherits the advantages of both orthogonal and non-orthogonal transmissions. In this scheme, the authors partitioned the available bandwidth among the users into identical orthogonal subbands according to their CSI information. As a result, intercluster interference is eliminated, and an improved QoS is achieved. With this scheme, the number of MUDs reduces, which results in reduced receiver complexity. Moreover, the authors also developed a user pairing technique to reduce inter-cluster interference. A gamma function approximated the probability density function (PDF) of the received SINR under Rayleigh fading distributions to derive the outage probability.

g: Comparison of existing NOMA schemes based on MIMO

Table 10 provides the detailed relative comparison of existing variants of NOMA used in MIMO using parameters such as transmission scenario, advantages, open issues, outage probability, bit error rate, throughput, EE, sum rate, UL, and DL.

J. MASSIVE MIMO

In 5G, massive MIMO (mMIMO) is a key enabler with large antenna diversity at a lower cost [189]. Its advantages are as follows (i) improvement of SE and EE of the network, (ii) reduction in latency, (iii) mitigation of an inter-cluster and inter-user interference, (iv) robustness against intentional jamming, and (v) improved SNR for the receiver. The authors in [190] integrated NOMA with mMIMO with limited feedback. In this technique, the transmitter of the BS consists of a large number of antennas compared to the number of users. To simplify the design, it decomposed the channels of massive MIMO-NOMA into multiple SISO-NOMA channels. Its performance was analytically derived in terms of an exact expression of OP and diversity order.

TABLE 10: Relative comparison of existing NOMA schemes based on MIMO

Problem in MIMO	**NOMA variants**	**Scenarios**	**TS**	**SR**	**OP**	**EE**	**BER**	**SE**	**Th**	**Advantages**	Open Issues
Multiple antennas at Transmitter enhance the complexity, cost and consumption	TAS-NOMA [162]	MU-MISO	DL	✓	×	×	×	×	×	Reduces the complexity, cost and power consumption	Imperfect CSI and need to find the ESC and OP
Joint antenna selection at both the BS and users	$AIA-A^3-AS$ [164]	MU-MIMO	DL	✓	×	×	×	×	×	AIA-AS provide better user fairness and A^3-AS provide near-optimal sum-rate performance	Imperfect CSI
Low SE of CEUs	NOMA-SSK [165]	MU-MIMO	DL	×	×	✓	✓	✓	×	Reduces decoding complexity at the receivers and reduce the interference of CEUs.	Power allocation scheme need to be determined.
Low SE of CEUs	NOMA-GSSK [167]	MU-MIMO	DL	×	×	✓	✓	✓	×	Reduces the computational complexity	Need to study the scheme with SIC
Secure group communication	PD-NOMA-SSK [168]	MU-MIMO	DL	×	×	×	✓	✓	×	Improves the network throughput	Study the power allocation problem for multiple adjacent users
Inaccurate MCS selection problem originated from implicit feedback	NOMA-HARQ [169]	SU-MIMO	DL	×	×	×	×	✓	×	Improved the cell throughput by 4% and cell edge throughput by 5% than HARQ algorithm	Extension to MU-MIMO system.
Inter cluster and Inter user interference	NOMA-BF [172]	MU-MIMO	DL	✓	×	×	×	×	×	Increases the number of supportable users and QoS of the weak users can be guaranteed	Imperfect CSI and SIC need to be studied.
Inter-cluster and inter user interference	NOMA-BF [173]	MU-MISO	DL	✓	×	×	×	×	×	Minimizes the total transmit power	Extension to MU-MIMO and mMIMO systems.
Inter cluster and Inter beam interference	RANDOM-BF-NOMA [174]	MU-MIMO	DL	×	×	×	×	×	✓	Reduces the CSI feedback and increase the throughput of CEUs	Performance over imperfect SIC is need to be evaluated.
Inter cluster	ZF-BF-NOMA [175]	MU-MIMO	DL	×	×	×	×	✓	✓	Maximizes the overall throughput in a cell	Multicell scenario need to be investigated
Worst case uncertanities	ROBUST-BF-NOMA [176]	MU-MISO	DL	✓	×	×	×	×	×	Investigate the scheme with imperfect CSI and maximizes the worst case achievable sum rate	Extend the scheme for MU-MIMO scenario, and need to eliminate the NOMA interference arise due to imperfect SIC.
	ROBUST-BF-NOMA [178]	MU-MISO	DL	×	✓	×	×	×	×		
	ROBUST-BF-NOMA [177]	MU-MIMO	DL	✓	×	×	×	×	×		
Inter cell and inter cluster interference	C-BF-NOMA [179]	MU-MIMO	DL	×	×	×	×	×	✓	Increases the CEUs throughput and improves the user fairness	Need to eliminate the NOMA interference arise due to imperfect SIC.
Inter and intra beam interference	BD-NOMA [180]	MU-MIMO	DL	✓	×	×	×	×	×	Performance gain increases from 10% to 20%	Investigate short term feedback with long term feedback and random user distribution with more users and clusters need to be studied
Transmit power	VP-NOMA [181]	MU-MISO	DL	✓	×	×	×	×	×	Minimizes the total transmit power	System may be extended to MU-MIMO.
Sum rate	NOMA-MRT [182]	MU-MISO	DL	✓	×	×	×	×	×	Adaptive switching method maximizes the weighted sum rate	Need to be extended for MIMO and mMIMO systems.
Inter-user interference	NOMA-SM [183]	MU-MIMO	DL	×	×	×	✓	×	×	Enhanced SE and eliminate inter-user interference	Need to increase the number of radio frequency at the transmitter side.
Inter-cluster interference	SA-NOMA [184]	MU-MIMO	DL/UL	x	✓	×	×	×	×	Provides large diversity gain	Imperfect CSI and SiC need to be studied.
Transmission power	H-NOMA [185]	MU-MISO	DL	×	✓	×	×	×	×	Reduced the transmission power	Same scenario need to studied for MIMO-NOMA system
Inter and Intra cluster interference	PH-NOMA [186]	MU-MISO	DL	✓	✓	×	×	×	×	Minimizes the total power consumption and eliminate the inter cluster interference	Same scenario need to studied for MIMO-NOMA system
Small packet transmission	QR-NOMA [187]	MU-MIMO	DL	×	✓	×	×	×	×	QoS of the users can be guaranteed, suitable for critical and real time applications, and channel conditions of user's are different.	Similar scheme need to be applied for V2X system.
Resource allocation	SBD-NOMA [188]	MU-MIMO	UL	✓	✓	×	×	×	×	Reduced receiver complexity and provides better sum rate	The system need to be studied for imperfect CSI, and Nakagami-m fading channels need to be examined.

Note- 1: Sum rate, 2: Outage Probability, 3: EE, 4: Bit error rate, 5: Spectral efficiency, 6:Throughput
TS: Transmission scenario, DL: Downlink, UL: Uplink
Notations- ✓: Yes, and ×: No

In [191], the authors combined NOMA and IDMA techniques for MU-mMIMO transmission. In this technique, the gain of the MU-mMIMO transmission was affected at a large rate with perfect CSI at the BS. To resolve it, the authors used IDMA and iterative data aided channel estimation (DACE) scheme with imperfect CSI, which provides high throughput and robustness against the pilot contamination problem. It is observed that for 5G networks, group-oriented applications were used with a multicast infrastructure used in 5G applications. The authors in [192] implemented a multicast 5G infrastructure with the combination of NOMA and mMIMO techniques. In [192], the authors proposed a hybrid unicast/multicast precoding scheme based on NOMA. The scheme first separates unicast users in NOMA and non-NOMA types and then eliminates the signal leakage using null space and the SIC technique. Moreover, enhancing SE superimposed the NOMA user's signals onto the multicast users' signals.

The concept of SA-MIMO-NOMA was used in [184], and the authors in [193] designed an interference cancellation combining (ICC) matrix to eliminate the intra-pair-interference in the mMIMO-NOMA system to limit the number of antennas between the BS and users. Moreover, to enhance the sum rate and decrease OP, the authors proposed a user pairing and pair scheduling algorithm (UPaS), which selects each group's first and second user. In [194], the authors analyzed the performance of massive access MIMO system instead of mMIMO. In this scheme, a Gaussian message passing iterative detection (GMIPD) algorithm was used for mean, and variance computation as compared to the mean square error multiuser detection scheme used in [195].

In [196], distinctive power is distributed to various users. According to the increase in allocated power, each user was arranged within each sub-band along with the NOMA encoding scheme. In this scheme, the transmission was divided into two phases: In the first phase, a NOMA encoding strategy was used to encode the data, and a transmitter was used to handover this to relay, while in the second phase, a relay transfers the encoded data to the receiver. In this way, the edge users have a fast transmission rate, where the relays are the CCUs or the access point. Moreover, it extends the coverage area and enhances the QoS performance for CEUs. In this NOMA scheme, the authors applied the maximum mean square error (MMSE)-SIC technique at the receiver side to decrypt the data and determined the closed-form expression for SINR, system capacity, and sum rate.

K. CELL FREE MASSIVE MIMO

Cell-free massive MIMO (CF-mMIMO) systems is a technique that is used to serve a large number of users while fully utilizing spatial multiplexing [197]. CF-mMIMO employs a large number of distributed APs for simultaneous transmission and is devoid of cell boundaries [197]. As such, CF-mMIMO suffers less from adverse effects due to spatially correlated fading and shadowing. Moreover, as the AP density grows large, users are guaranteed to be near at least one AP [198]. However, these advantages come at the cost of additional backhaul requirements as the APs need to be fully connected through a central processing unit [199]. When NOMA is integrated with CF-mMIMO, it increases the SE, reduces the latency, and supports the massive connectivity. The authors in [200] integrated NOMA with CF-mMIMO to overcome the problem of NOMA-aided mMIMO (imperfect CSI at APs, imperfect SIC, and statistical CSI). In this, the authors investigated the design of CF-mMIMO-NOMA systems. Superposition-coded signals are spatially multiplexed via conjugate beamforming into multiple user clusters in the same time-frequency RB by the APs. The users within each cluster are served via PD-NOMA with user-ordering and SIC. An achievable sum rate is derived for a design of a practically viable CF-mMIMO-NOMA system. The authors in [201] studied how NOMA improves the achievable rate of a cell-free massive MIMO system under random base station deployments. Here, homogeneous PPPs were used to model the random user and AP locations, and APs were assumed to be connected by a perfect backhaul network via a CPU. Moreover, a Rayleigh fading environment with long-distance path loss was assumed. The TDD mode was used with periodic uplink pilots to estimate CSI and two user NOMA clusters for the downlink. In [202], the authors investigated the NOMA-based CF-mMIMO system relying on both conjugate and normalized conjugate beamforming techniques. In contrast to [200], [201], and [202] the authors in [203] studied the CF-mMIMO-NOMA system with underlay spectrum-sharing. Similar to [203], authors in [204] analyzed the achievable rate of a CF-mMIMO-NOMA (secondary) and massive MIMO (primary) system. Here, the authors used SU clustering based on Jaccord coefficients and derived the closed-form sum rate expression of the secondary network considering joint effects of intra-cluster pilot contamination, inter-cluster interference, imperfect SIC, and statistical downlink CSI at SUs. Numerical results proposed that the cognitive CF-mMIMO-NOMA system supports significantly more SUs compared to the OMA-hybrid.

L. SOFTWARE DEFINED NETWORKING

Xu *et al.* [205] proposed an evaluation criterion to analyze the performance gain of NOMA over TDMA. Authors in [205] first illustrated the relationship between the capacity region of Gaussian BC and two rate regions using NOMA and TDMA. Then, they proposed an evaluation criterion for NOMA using wireless fading scenarios. This evaluation criterion was used to study the sum rate and individual data rates statistically. Moreover, the authors also proposed a user pairing and optimum power allocation scheme for the DL scenario. They analytically showed that NOMA with TDMA outperformed the other schemes using parameters such as the sum rate and data rate.

M. WIRELESS SENSOR NETWORKS

Wireless Sensor Networks (WSNs) are low-cost and low-power homogeneous or heterogeneous sensors that are used for sensing, computations, and short-range wireless communications [206]. But, the key challenges of these sensors are their energy depletion which results in limited lifetime [207] [208]. To resolve these issues, NOMA technology is integrated with WSN. For example, the authors in [209] investigate the problem of maximizing the EE of NOMA-based WSN. They used energy harvesting to improve the energy of the sensors. To solve this problem, the authors proposed a particle swarm optimization-based algorithm. The simulated results showed that the proposed algorithm achieved the convergence equivalent to the global optimum solution. In [210], the authors studied the problem of interference due to the sharing of spectrum between the sensors and other sources by using stochastic geometry. The main aim of this scheme was to provide massive connectivity between the sensors using NOMA. Also, the authors in [210] evaluated the performance of the proposed scheme using OP, average link throughput, and energy consumption efficiency, where results showed that NOMA performed better than OMA. In [211], the authors proposed a solution to maximize the lifetime of a single hop WSN. The authors in [212] proposed a power allocation scheme for NOMA-based underwater acoustic sensor networks. The equal transmission times (ETT) power allocation scheme prevents resource wastage by ensuring the transmission time between each transmission path.

N. MOBILE EDGE COMPUTING

NOMA and Mobile Edge Computing (MEC) are integrated to avoid the delay and to reduce the energy consumption of the MEC network. In [213], the NOMA-based MEC network was used such that the SIC-based BS is selected to perform the computation tasks from different users to ensure the offloading. In contrast to [213], the authors in [214], analytically proved that the latency and energy consumption are reduced when uplink and downlink NOMA are combined with MEC. The authors in [215] and [216] studied the NOMA-based MEC networks to minimize time and energy consumption. It was found that the authors from [213]–[216] applied NOMA only on one group of users and ignored the time allocation procedure among different group of users. So, to resolve this issue, the authors in [217] proposed the resource allocation scheme among different groups of users by using uplink NOMA transmission over MEC. The main aim was to provide an energy-efficient scheme that provides better results than the conventional OMA. In [218], the energy consumption of NOMA-MEC networks was minimized by assuming that each user has access to multiple bandwidth resource blocks. To minimize the network's energy consumption, the authors in [219] combine the EH technique with the NOMA-based full-duplex MEC network. They achieved the target by using power control, schedule, and computation capacity allocation.

O. UNMANNED AERIAL VEHICLES

To improve the coverage and SE of 5G, Unmanned Aerial Vehicle (UAV) communication with NOMA technique plays a vital role. Since NOMA works effectively under asymmetric channel conditions, this property of NOMA is suitable for UAVs due to high mobility, which enhances the performance gain of the network. In [220], the authors studied the bit allocation, and trajectory optimization framework for UAV mounted cloudlet for offloading applications in NOMA. The results demonstrated that the proposed scheme enhances the EE of mobile users. The authors in [221] deployed the fixed-wing UAV communication with NOMA for ground users, which are located at areas where the BS coverage does not exist. The authors also proposed a multiple-access mode selection (NOMA/OMA) scheme to ensure guaranteed communication for ground users as per their outage probability requirements. In contrast, to [220] and [221], the authors in [222] investigated the NOMA with an aerial BS, where they addressed the problem of coverage and capacity by assuming performance thresholds for both cell-edge as well as the CCUs.

In [223], the authors applied the NOMA technique with UAV to enhance the coverage of user region which is densely packed, such as stadium, malls, or a concrete area. Furthermore, a beam scanning approach was used to find the optimal area that radiates within the user region. Based on this, a hybrid transmission strategy was applied to all the users at a time in the presence of NOMA. The result showed that user distance feedback is a better alternative compared to full CSI feedback, especially for the rapid fluctuation channels for NOMA rather than OMA. In [224], the authors studied the three cases of NOMA-enabled UAV communication. In the first case, the author evaluated the performance of NOMA-enabled UAV communication by using stochastic geometry for position estimation of UAVs and ground users. In the second case, they investigated the two-dimensional (2D) model for position estimation of UAVs by assuming that UAVs can fly at a fixed height. In the last and third case, they analyzed how machine learning algorithms can be applied for UAVs localization. Authors in [225] applied MIMO-NOMA on UAVs by using stochastic geometry, by considering the locations of NOMA users and interference sources. In [226], the authors applied the concept of NOMA transmission with UAV assisted wireless backhaul network and proposed a novel cooperative NOMA strategy to boost the performance of the system. Authors in [227] proposed a cooperative NOMA scheme to eliminate the uplink interference from sharing the same channel between the UAV's LOS and the BS cellular-connected users. In contrast to [227], the authors in [228] studied the UAV uplink communication in the cellular network. In this scheme, UAVs have multi-antennas to transmit multiple data streams to a large number of ground base stations to serve a terrestrial user at the same time over the same frequency band. Also, the authors in [228] proposed a NOMA-based transmission strategy that is used to mitigate the signals received from the UAVs and the terrestrial users' signals.

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P. ULTRA-DENSE NETWORK

Ultra-Dense Network (UDN) is a technology used in 5G to reduce the distance between the BS and users. This technique increases the number of connections between the BS and users and improves the data rate of the CCUs and CEUs, respectively. In [229], the authors used the concept of PD-NOMA in UDN for multi-user access. The authors applied the matching algorithm for resource allocation and the difference of two convex programmings for power allocation. By using these two concepts, the authors enhanced the throughput of the network. In contrast to [229], the authors in [230] also enhanced the throughput of the network by using the PD-NOMA-based user-centric framework. This scheme converted the mixed-integer non-linear programming (MINLP) problem into an access points grouping problem. To solve this problem, a low complexity-based sub-optimal matching algorithm was implemented. Then, the authors in [231] proposed user pairing and designed a new resource allocation algorithm to have a flexible configuration in heterogeneous UDN.

Q. VISIBLE LIGHT COMMUNICATION

Visible Light Communication (VLC) is a small cell technology used in 5G to provide ubiquitous broadband connectivity for indoor areas. It has an unlicensed spectrum of an order of terahertz (430 THz-790 THz) which is currently unused in wireless communication. As per the report of [1], it was found that 70% of the data traffic is originated from indoor areas. So, when VLC is integrated with the existing fiber networks, its unlicensed spectrum offloads the data traffic. Generally, light-emitting diodes (LEDs) are used to provide VLC in both indoor and outdoor scenarios. Using LEDs, the cost of broadband connection reduces, and data transmission speed over white light increases. This consists of two techniques: intensity modulation (IM) and direct detection (DD). In IM, the intensity of light generated by LEDs varied as per users' location, whereas, in DD, photo-detectors are used at the receiver side, which detects the variation in the intensity of light. The light signals from LEDs cannot penetrate through the walls, so intercell interference does not exist. Due to this advantage, visible light provided secure communication and improved the QoS of the CEUs. Despite the aforementioned benefits, VLC has limitations that need to be addressed to exploit its potential benefits fully. The major limitations of VLC are i) it has narrow modulation bandwidth due to which achievable data rate cannot be achieved and ii) in multiple cells scenario the problem intercell interference becomes severe. So, to resolve these problems, integration of NOMA is required with the following example researches.

1) Gain ratio power allocation [232]

It is a gain ratio power allocation (GRPA) scheme where power allocated to k^{th} user is given by $P_k = (\frac{h_1}{h_k})^k P_{k-1}$. The authors in [232] assumed that the user's actual channel conditions are based on fair power allocation. To avoid overlapping between the cells, a cell zooming technique was proposed, where transmitting angles of the LEDs are adjusted to control the size of cells. Sometimes, adjusting the transmitting angles may affect the width and intensity of beams, resulting in the undesired illumination across the indoor space. So, to overcome this issue, a location-based user association strategy was proposed. With this strategy, users may remain connected with those two LEDs, which create an overlapping area. Moreover, to enhance the performance of CEUs, tunable FOVs were used to decrease the number of handovers at the PDs.

2) OFDMA-NOMA [233]

It is a hybrid multiple access technique designed for bidirectional VLC transmission [233]. The combination of both these techniques enlarges the capacity of the system to provide services to a large number of users. It provides high SE, high throughput, and high tolerance against multipath-induced distortion. The performance of the proposed scheme was experimentally demonstrated using the optimum power allocation ratio (PAR). The results show that the PAR values for both uplink and downlink transmission were about 0.25. Moreover, to eliminate the inter-user interference, the authors in [233] also investigated the effect of channel estimation. The obtained results demonstrated that the channel estimation like intra-symbol frequency averaging (ISFA) and minimum mean square error (MMSE) perform better than least square.

3) NOMA-SCFDM [234]

In this, the authors combined the NOMA technique with single carrier frequency division multiplexing (SCFDM). Similar to [233], this scheme also provides high SE, high throughput, and high tolerance against multipath-induced distortion, but it lowers the value of PAPR. The authors experimentally demonstrated the feasibility of this scheme and proved that it provides better results than the NOMA-OFDM in terms of BER.

4) NOMA-PON [235]

The authors proposed a single carrier transmission-based NOMA for bidirectional passive optical network (PON) transmission. In this scheme, the power domain-based SC technique was used to multiplex the optical network units (ONUs) signals at the transmitter side, and frequency domain successive interference cancellation (FD-SIC) was used to separate the ONU signals at the receiver side. So, all ONUs efficiently utilized the whole time-frequency resources. An efficient power allocation technique was proposed to provide better trade-offs between the system throughput and user fairness. The main aim of the proposed scheme was to achieve optimum PARs. The authors also proposed a polarization dimension and joined detection techniques to enlarge the transmission capacity and analyze the BER. The results show that the optimum power difference between the two ONUs for upstream was 7 dB, and optimum PARs for downstream was 0.25. The BER performance for both these

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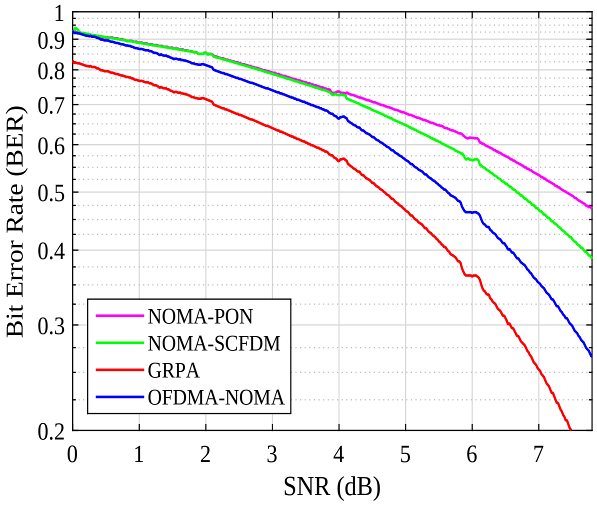

FIGURE 22: Comparison of various NOMA schemes for VLC Communication

streams equals 10^{-3}. In contrast, to [235], the authors in [236] integrate MIMO and polarization interleaving technique with the NOMA-PON transmission scheme so that the capacity of the system can be increased and a large number of users can be served. Moreover, the authors also studied the MIMO channel estimation technique concerning ISFA and MMSE to eliminate the inter-user interference and the crosstalk between polarizations. The results showed that for four users, the proposed transmission scheme achieved an optimum PAR of 0.42.

5) DCO-OFDM-NOMA [237]

Direct current biased optical orthogonal frequency division multiplexing (DCO-OFDM) technique was used in the VLC system to convert the bipolar OFDM signal into a unipolar one. In [237], the authors integrated the NOMA technique with DCO-OFDM to enhance the system SE. In this scheme, the authors studied the impact of clipping in terms of attenuation and clipping noise through asymmetrical double clipping technique. They have analyzed the scheme in terms of achievable rate regions and proved that it outperformed the OMA-DCO-OFDM.

6) FTN-FrCT-NOFDM [238]

Faster-than-Nyquist-Fractional cosine transform-non-orthogonal frequency-division multiplexing (FTN-FrCT-NOFDM) scheme provide real-valued signal as compared to FrFT-NOFDM [238]. It can be directly applied to the VLC system without up-conversion, making it more suitable for cost-sensitive VLC systems. It consumes lesser bandwidth as compared to FrFT-NOFDM, resulting in low-frequency distortion and high SE. The simulated results show that FrCT-NOFDM performs better in terms of BER and achieved higher security than FrFT-NOFDM.

Comparison of various NOMA schemes based on VLC

- Table 11 provides the detailed relative comparison of existing variants of NOMA used in VLC regarding parameters such as the transmission scenario, technique used, merits, throughput, EE, capacity, latency, and open issues.
- Fig. 22 shows the effect of varying the SNR on the BER. The result implies that GRPA achieves lower BER than the OFDMA-NOA, NOMA-SCFDM, and NOMA-PON. The system model, parameters, and environment used in the simulation are taken from [232]. In GRPA, the user's actual channel conditions were based upon the fair power allocation among them. To avoid overlapping between the cells, a cell zooming technique was used, where transmitting angles of the LEDs were adjusted to control the size of cells. Also, adjusting the transmitting angles may affect the width and intensity of beams, resulting in the undesired illumination across the indoor space. So, to overcome this issue, a location-based user association strategy was used. These advantages show that GRPA is more suitable for VLC communication.

R. MILLIMETER WAVE

The frequency range of Millimeter Wave (mmWave) in the electromagnetic spectrum is from 30-300GHz [239], which shows that it provides a huge amount of bandwidth for 5G to handle the high data rate. Despite its large bandwidth, it has some disadvantages like poor foliage penetration, and free-space path loss [240], which degrades the QoS to the end-users in ultra-dense networks. To overcome these disadvantages of mmWave, various authors integrated NOMA. When NOMA is integrated with mmWave, then it provides the following benefits: (i) supports massive connectivity, (ii) amenable with mmWave correlated channels, (iii) increased the throughput due to reduction in inter-beam interference, (iv) reduced the hardware cost. By exploring these advantages, the authors provided the following variants of NOMA with mmWave.

1) Random-BF-NOMA [241]

In this, the authors studied the combination of mmWave with NOMA. In this scheme, the BS without knowing the CSI generates a single random beam for each user. Due to the presence of mmWave, the beam behaves like a directional antenna, and users having low signal strength do not take part in the scheduling. As a result, the overhead of the system gets reduced. To analyze the performance of this technique, the authors used thinning scheme aided stochastic geometry model to study the blockage features of mmWave. Moreover, to reduce the system overhead, the authors' proposed two beamforming techniques (i) low feedback transmission scheme and (ii) one-bit feedback scheme. In the first scheme, the BS already knows the users' distance, while in the second scheme, one user sends one bit as feedback to the BS. The authors also investigated the scenario of multiple beams generation from the BS, where mmWave suppressed the inter-beam interference. The numerical results showed that the

TABLE 11: Parametric analysis of existing NOMA schemes in VLC

Problem in VLC	NOMA Variant	Transmission scenario	Techniques	Performance metrics						Merits	Open issues
				1	2	3	4	5	6		
Narrow modulation bandwidth	GRPA [232]	Downlink	Gain ratio power allocation	×	×	✓	×	×	×	Maximize the users' sum rate and decrease the number of handover by tuning the field of views (FOVs)	Scheme needs to be analyzed for UL scenario.
Flexible bandwidth allocation	NOMA-OFDMA [233]	UL & DL	Hybrid scheme for VLC transmission.	×	×	✓	✓	✓	×	Efficient channel estimation are used to eliminate the inter-user interference and improved system capacity.	Outage probability needs to be derived.
Lower BER & Less tolerant to LED non-linearity	NOMA-SCFDM [234]	Downlink	Integrate NOMA with SCFDM	×	✓	✓	✓	×	×	Improved BER than NOMA-OFDM.	Can be extended to Multi- carrier frequency division multiplexing.
Broadband Access	NOMA-PON [235]	Downlink & Uplink	Single carrier transmission with NOMA and FD-SIC	✓	×	×	✓	×	×	Lower BER and PAPR is achieved.	Needs to be analyzed the throughput.
Effect of clipping	DCO-OFDM [237]	Downlink	Clipping process is proposed	×	×	×	×	✓	×	Enlarge the achievable rate region and provide unipolar signal.	Dynamic power allocation scheme is required.
Higher bandwidth	FTN-FrCT-NOFDM [238]	Downlink	Joint spectrum resource and subchannel transmission power allocation, and Sensing time selection	✓	×	×	×	×	×	Directly used in VLC systems without upconversion, cost sensitive, and save the limited bandwidth	An effective algorithm is required to mitigate the inter cluster interference.

Note- 1: Bit error rate (BER), 2: High Tolerance 3: Throughput, 4:PAPR, 5: Capacity 6: Spectral Efficiency
Notations- ✓: Yes,and ×: No

proposed schemes outperformed the traditional mmWave-OMA schemes. In contrast, to [241], the authors in [242] studied the user scheduling and power allocation algorithms for mmWave NOMA systems with random beamforming under partial CSI feedback. To achieve the suboptimal and low complexity solution, they used the matching theory for user scheduling and successive convex approximation for power allocation. In addition, the proposed mmWave NOMA systems are capable of outperforming conventional mmWave OMA systems in terms of sum rate and the number of served users.

2) FRAB-NOMA [243]

The authors studied the effect of combining NOMA with finite resolution analog beamforming (FRAB) technique. In this scheme, users' channel conditions do not match with each other. The authors proved that when NOMA is exploited with FRAB, multiple users easily share the single beam and can communicate concurrently. The degree of freedom induced by mmWave decreases. The numerical results of FRAB with NOMA outperformed the conventional NOMA schemes.

3) Beamspace MIMO-NOMA [244]

This scheme was proposed to overcome the limitation of mmWave. In this scheme, the number of users who participate in the beamspace-MIMO scheme must be larger than the number of available resource blocks. The authors in [244] integrated NOMA with beamspace-MIMO to get the high spectrum and EE. So, to reduce the inter-beam interference, a precoding scheme based on the principle of zero-forcing was designed. Moreover, to allocate the power dynamically, they proposed a low complexity-based iterative optimization algorithm to have a high sum rate.

4) EEPA-NOMA [245]

In this, the authors optimized the problem of EE in the mmWave-mMIMO-NOMA system. They integrated NOMA in this system to correlate the users' channel. To reduce the complexity of the hardware, the authors applied a low RF chain structure at the BS with the hybrid analog/digital precoding scheme. Firstly, paired users were formed in a cluster based on channel correlation and gain difference. Then, analog beamforming was applied in each cluster as per their codebooks. Also, to reduce the inter-cluster interference, the ZF precoding scheme was applied to the strong channel condition users. Moreover, the authors proposed an iterative power allocation algorithm per cluster to maximize the users' EE as per their QoS requirements. The numerical results show that the proposed scheme provides better EE as compared to OMA schemes.

5) HB-NOMA [246]–[249]

In the above-mentioned schemes, the authors combined NOMA with mmWave by using only baseband precoders/combiners. Also, the authors in [246] and [248] proposed hybrid beamforming (HB) in mmWave-NOMA systems. In [246], the authors studied the joint power allocation and beamforming scheme to maximize the sum rate of two-user mmWave NOMA using an analog beamforming structure with the phased array. In [248], the authors analyzed that when HB is integrated with the mmWave-NOMA system, then digital precoders of the BS are not perfectly aligned with the user's effective channel. Based on the imperfect aligned beams, the authors in [248] also proposed a power allocation algorithm to maximize the sum rate of the system. But, they did not consider the effect of imperfect beamforming for analysis of the sum rate. Also, the authors in [249] provide the imperfect correlation in HB for multi-users. In this proposal, the authors first formulated the expressions of the sum rate for HB-NOMA and then proposed a sub-optimal algorithm to maximize it. Then, they derived a lower bound for the achievable rate by assuming that the angle between the highest channel gain MUs and the other MUs is non-zero. The results obtained show that the proposed scheme has a loss in data rate due to inter-cluster interference between the MUs. In addition, to [249], the authors in [247] studied the impact of imperfect correlation between the effective channels. They maximized the sum rate of the HB-NOMA system in three steps using power constraints. In the first step, they used analog precoders/combiner, and in the second step, digital precoders are used, and at last, a sub-optimal power allocation was introduced. Also, they proposed a lower bound for each user under perfect and imperfect correlation. The results obtained demonstrated that with perfect correlation, the sum rate is equivalent to digital precoders, while with imperfect correlation, it depends on the correlation factor. The obtained results show that the proposed scheme has an optimal sum rate compared to conventional HB-OMA systems.

6) Cluster-based mmWave NOMA [250]

In this, the authors investigated the designs of user clustering and power allocation algorithms for mmWave-NOMA systems. In this, the users follow a spatial clustering distribution model. Channel correlations provide an efficient measurement that facilitates the implementation of K-means-based clustering. Furthermore, they developed a closed-form expression for the optimal power allocation for each cluster, assuming that the power is equally allocated over each cluster. Authors claimed that the proposed K-means enabled machine-learning framework for mmWave-NOMA systems outperforms mmWave-OMA systems.

7) JA-STSK-NOMA [251]

In this, the authors studied the JA-STSK and JA-MS-STK schemes with NOMA to replace the STSK scheme in MC-IDMA and SC-IDMA, respectively. The objective of the proposed scheme was to acquire high throughput without high complexity. Also, the authors proved that when JA-STSK and JA-MS-STK schemes are integrated with a fair AA algorithm, these have higher throughput as compared with the random AA selection algorithm. Moreover, they also demonstrated that when MC-IDMA is integrated with IRCC, then the proposed scheme provides an increase in throughput with lesser decoding complexity than OMA. The results show that this scheme reduces computational complexity concerning CFRs and has a significant BER performance.

S. TERAHERTZ COMMUNICATION

Terahertz (THz) communications have higher frequency bands than mmWave. Its frequency range from 0.1 THz-10 THz, which lies between infrared and microwave. The THz band can achieve up to $(10^3 - 10^4)$ higher magnitude than the current wireless communication band commonly used in mobile phones, which can provide huge communication bandwidth [252]- [253]. The main advantages of THz communications are (i) large capacity, (ii) good direction, (iii) strong confidentiality, (iv) strong anti-interference ability, and (v) suitable for the ultra-high-speed and short-range indoor communications. Despite these advantages, THz wave has some disadvantages, which are as follows [253]: (i) larger transmission attenuation loss (ii) high-speed broadband wireless communication (iii) atmospheric molecule and water droplet absorption attenuation (iv) create path loss peaks and produce spectral windows drastically change the communications distance (v) smaller coverage area (vi) heavy transmission burden and (vii) large energy consumption [253]. To overcome these disadvantages and obtain a communication rate of 10 Gbps or more, the authors integrated NOMA with THz. When NOMA is integrated with THz, it provides the following benefits [254]: (i) enhance network capacity (ii) improve resource utilization, (iii) support ultra-massive machine type of communication, (iv) enable the energy-efficient system, and (v) ultra-high reliability and low latency. The variants of NOMA with THz are as follows:

1) THz-NOMA [255]- [256]

In this, the authors proposed a downlink THz-NOMA scheme, in which the hybrid beamforming is adopted to form user clusters. Each cluster consists of four users with two NOMA groups. First of all, the authors formulated the Beamforming-Power-Bandwidth (B-P-B) problem to maximize the network throughput while satisfying the QoS requirement of each user. Then, the beamforming sub-problem is designed by the BS based on the THz-NOMA architecture and the user distribution information. After the beamforming design, the Power-Bandwidth (P-B) resource allocation problem is investigated to obtain the full benefit of the THz-NOMA system in terms of the power allocation and sub-band assignment. The Hungarian algorithm solves the sub-band allocation based on Long-User-Central-Window (LUCW) principle. Then the power assignment is conducted by an iterative method. The authors claimed that the proposed scheme achieved 928.4 Gbps speed as compared to the OMA system. In contrast, to [255], the authors in [256] proposed the Energy-Efficient Resource Allocation in THz Downlink NOMA Systems. The authors in [256] decrease the energy consumption triggered by increasing of wireless services. Here, a subchannel assignment algorithm and a power optimization based on the alternative direction method of multipliers (ADMM) algorithm are developed to improve the EE of THZ-NOMA systems.

2) THz-MIMO-NOMA [257], [258], [259]

In [257], the authors designed the user clustering and hybrid precoding scheme to maximize the EE in the THz-MIMO NOMA systems. The authors proposed a fast convergence scheme for user clustering in the NOMA-MIMO system by using an enhanced K-means machine learning algorithm to achieve the target. Next, the hybrid precoding scheme based on the sub-connection structure reduces the consumption of power and implementation complexity. Furthermore, authors in [258] proposed an extended scheme given in [258] In its extended scheme, authors consider the fronthaul link capacity constraint to maximize the EE of THz-NOMA system with imperfect SIC. To achieved this, the authors used the distributed ADMM algorithm for power allocation. The numerical results demonstrated that the proposed scheme acquires faster convergence, higher EE, and lower power consumption for the THz cache-enabled network. In contrast to [257] and [258], the authors in [259] proposed a low complexity subspace detectors for THz MIMO-NOMA systems. Here, an adaptive spatial tuning technique is used to allocate NOMA resources and enhance channel conditions. The detectors are studied analytically by deriving approximate error probability expressions and empirically via simulations of single-user and multi-user scenarios. Also, a low complexity-based joint clustering and power control scheme is used for THz distance-based path-loss parameter to guarantee efficient SIC demodulation.

3) Cooperative THz MIMO-NOMA [260]

In [260], the authors investigated a cooperative MIMO-NOMA THz system model with HD/FD relaying. An optimal power allocation of the NOMA coefficients has been derived to maximize the achievable data rates for both HD and FD modes. Numerical results showed that the optimal scheme outperformed the fixed scheme in terms of the sum rate in HD/FD mode. However, as the number of antennas increases, the fixed and optimal models have the same performance. Also, the effect of distancing between the available nodes along with the number of antennas was studied. It showed that in HD mode, the distance between BS and relay node has a much higher effect than the distance between BS and user equipment 2.

T. HETEROGENEOUS NETWORKS

Heterogeneous Networks (HetNets) in 5G is used to enhance the coverage and capacity for the users in an ultra-dense network [261]. In these networks, low-power BSs such as FBS and PBS are deployed under MBS. The presence of low-power BSs near the UE also improves EE due to less battery power consumption. But, the problem of co-channel and cross-channel are severe in these networks, which in turn affects SE. To fully exploit the potential benefits of this network, the authors integrated NOMA with HetNets and proposed the following variants.

1) TIM-NOMA [262]

This is a hybrid scheme in which Topological Interference Management (TIM) and NOMA mitigate intercell interference and intra-cell interference, respectively, in a heterogeneous network [262]. It is applied to HetNets using user pairing and Kronecker Product representation. This scheme has twice the sum rate compared to TDMA for high SNR values and enhances the performance of cell-edges users of femtocells in terms of fair power allocation and QoS.

2) GFDM-NOMA [263]

It is a combination of generalized frequency division multiplexing (GFDM) and NOMA technique. GFDM is used to cover the OFDM and single carrier frequency domain, while NOMA improves the system capacity by serving many users from the same RB. The authors in [263] proposed a joint subchannel and power allocation scheme in this technique to handle two types of heterogeneous traffic, elastic and streaming. The main aim of this scheme was to maximize the weighted sum rate for elastic traffic users to minimize the sum rate for streaming users with subject to the constraint of subchannel and transmit power allocation. The numerical results demonstrated that the proposed scheme achieved approximately 31% enhancements in sum rate in comparison to OMA.

3) MBMS-NOMA [264]

In this, the authors explored how NOMA enhances the performance of a multimedia broadcast/multicast service (MBMS) system in HetNets. With this NOMA, two transmission techniques were studied, non-orthogonal multi-rate MBMS transmission (NOMRMT) and non-orthogonal multi-service MBMS transmission (NOMSMT). In this proposal, the authors proposed stochastic geometry and developed a tractable model to analyze performance using synchronous and asynchronous transmissions. The numerical results demonstrated that the proposed MBMS-NOMA scheme outperformed the MBMS-OMA.

4) JT-NOMA [265]

The authors in [265] analyzed the impact of power allocation to NOMA users in a multi-cell network. In JT-NOMA, all BSs in coordination with each other perform joint transmission for the remote users in a particular cell using the same RB. With this scheme, the SIC technique is used to separate the signals for remote users and decode the signals for far users. In this way, it mitigates the inter-cell interference and enhances the performances of all NOMA users. The numerical results showed that this scheme enhances the coverage and throughput for each user in HetNets.

5) NOMA-HCN [266]

In this, the authors proposed HetNets, where the first tier consists of MBS, and the second-tier has various FBS using NOMA. With this scheme, the authors offload the traffic from

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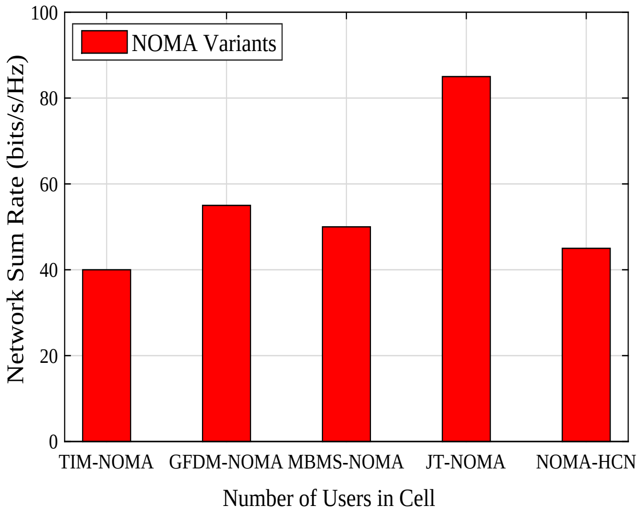

FIGURE 23: Comparison of various NOMA schemes for HetNets

MBS. The authors' main aim was to enhance the fairness and performance gain of the users located at the edge of the FBS cell by using CCUs. The numerical results showed that the proposed scheme improved terms of ergodic rate and user fairness.

6) Comparison of various NOMA schemes for HetNets

- Fig. 23 represents the graph between the sum rate and the number of users in the networks. The system model, parameters, and environment used in the simulation are taken from [265]. The graph implies that JT-NOMA outperforms the TIM-NOMA, GFDM-NOMA, MBMS-NOMA, and NOMA-HCN. As JT-NOMA mitigates the inter-cell co-channel interference and reduces the channel fading. Furthermore, in this scheme, all void BSs can do joint transmission to enhance the signal power of the farthest user in a cell, which improves the throughput of the users in a dense network with a moderate user intensity. Thus, JT-NOMA is most suitable as compared to the rest of the HetNets classification.

U. VEHICLE-TO-EVERYTHING

Vehicle-to-Everything (V2X) communication is a newly emerging technology in 5G used to provide improved user's travel experience and security, safety, and internet access services [267]. Despite these advantages, energy-saving, low latency, and faster packet transmission, and reception in an ultra-dense network of V2X are the issues that are required to be addressed. To resolve these issues, the authors integrated NOMA with this technique. When NOMA is integrated with V2X, then it resolved the problem of data congestion by accessing the channel non-orthogonally [268] and provides the following benefits (i) reduction of the transmission latency, (ii) support for massive connectivity, and (iii) enhanced SE and EE. But, the problems of improvement in link reliability, enhancement of bandwidth efficiency, and reduction in collision still need to be resolved. So, the following variants of NOMA in V2X communication are proposed.

1) NOMA-SM [269]

To improve the link reliability and to fulfill the high bandwidth requirements for V2V communication, the authors in [269] used NOMA with SM and massive TA. But, still, many challenges need to be resolved. For example, the authors in [269] proposed a new NOMA-SM scheme for V2V scenario with correlated Rician channel. They analytically derived the ergodic capacity of NOMA-SM by using Monte Carlo simulation. The results obtained show that the proposed NOMA-SM scheme improves robustness against the spatial and temporal effects of the V2V channel. Moreover, a power allocation algorithm was proposed to satisfy the QoS of low priority flow and maximize the throughput of high priority flow.

2) NOMA-MCD [270]

In this, the authors amalgamate NOMA with the mixed centralized/distributed (MCD) scheme. The main aim of this scheme was to provide decreased access collision and the increase in reliability of the network. In this scheme, the BS in a non-orthogonal manner used time and frequency resources, whereas dynamic power control and the iterative control signalling were used by the vehicles to achieve better performance. Also, the authors studied the scheduling and resource allocation problem in a cellular V2X broadcasting system. To resolve this, they used two multi-dimensional stable roommates (MD-SR) schemes. Then, the authors proposed a novel rotation matching algorithm. The numerical results show that the NOMA-MCD scheme reduces the latency and enhances the packet reception reliability compared to OMA-based V2X schemes.

3) Comparison of NOMA schemes for V2X

- Table 12 provides a detailed relative comparison of existing variants of NOMA used in V2X using parameters channel fading, a technique used, merits, bit error rate, latency, and packet reception reliability.
- Fig. 24 shows the effect on latency concerning the decoding rate threshold. The system model, parameters, and environment used in the simulation are taken from [270]. The graph implies that NOMA-MCD performs better than NOMA-SM and OMA with an increase in decoding rate. The NOMA-MCD reduced the packet collision up to a larger extent compared to the NOMA-SM and OMA schemes. This reason makes NOMA-MCD more suitable for 5G networks.

V. UNDERWATER ACOUSTIC COMMUNICATION

Underwater acoustic communication (UWAC) reigns the long-range wireless communications but suffers from low data rates due to acoustic signals' limited bandwidth and

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TABLE 12: Relative comparison of existing NOMA schemes based on V2X

Problem **in M2M**	NOMA **variants**	Channel **fading**	**Techniques**	**Performance metrics**			**Merits**
				1	**2**	**3**	
Inter antenna interference (IAI) and Doppler and fading effects	NOMA-SM [269]	Rician channel fading	Distributed power allocation	✓	×	×	Improved the link reliability and bandwidth efficiency of V2V transmissions, eliminates the IAI, and reduces the transmission latency.
Scheduling and resource allocation	NOMA-MCD [270]	Rayleigh channel fading	Rotation matching algorithm for sub-channel allocation and Tx-Rx selection and time slot allocation algorithm	×	✓	✓	Reduces the access latency, improves the packet reception probability, and reduces the access collision

Note- 1: BER, 2: Packet reception reliability, 3: Latency
Notations- ✓: Yes, and ×:No

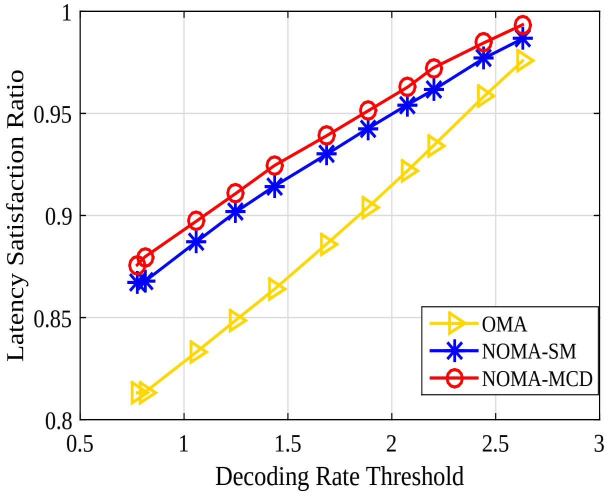

FIGURE 24: Comparison of various NOMA schemes for V2X

the highly variable delay due to acoustic signals' low propagation speed. Also, the underwater devices are power limited. Hence, relays are used to increase the power utilization efficiency, channel reliability, and transmission distance. To overcome this problem, the authors integrated NOMA with UWAC. When NOMA is integrated with UWAC, i) it improves the system spectral efficiency without additional resources, ii) resistance for carrier frequency offset, and (iii) reduces energy consumption. The variants of NOMA for UWAC are given as follows:

1) R-FD-NOMA [271]

In [271], authors integrated NOMA with UWAC to improve the sum rate of the UWA channel using a relay and FD. The presence of FD-NOMA allows multiple uplink and downlink transmissions to occur simultaneously, using the same time and frequency resources. The main challenge for this deployment is the interference between the transmissions. SIC and self-interference cancellation techniques are employed to mitigate the interference due to NOMA and FD, respectively. To maximize the sum rate, an optimization problem over the power is formulated. The authors claimed that the proposed R-FD-NOMA scheme achieved a higher sum rate than non-relay (NR)-FD-NOMA and relay (R)-HD-NOMA schemes.

2) TR-NOMA [272]

In this, authors studied a single-input multiple-output NOMA scheme with a passive-time reversal (TR) technique to reduce the time-frequency dispersion of the underwater acoustic channels. Here, a SWIPT-NOMA is used to harvest energy in downlink transmission from the transmitted signal. Numerical results demonstrated that the proposed scheme achieved higher BER and OP than the NC-NOMA and C-NOMA.

W. INTELLIGENT REFLECTING SURFACES

An intelligent reflecting surface (IRS) is a special technique that improves the coverage of the network. IRS consists of many passive elements that independently reflect the incident signal by adjusting the reflection coefficients. By doing so, the received signal power is boosted at the receiver. In contrast to AF relay, the IRS does not have the signal processing capability [273]. Also, the IRS is different from the active, intelligent surface-based mMIMO in terms of performance, affordable hardware cost, and tolerable power consumption [274], [275]. When NOMA is integrated with IRS, then it provides the following benefits: i) enhanced the channel conditions by adjusting the phase shift and amplitude of the IRS elements, and ii) provide additional paths to construct a stronger combined channel gain. Some of the variants of IRS-NOMA were given as follows:

1) IRS-NOMA [276]- [277]

In [276], authors studied the joint power allocation and phase shifts optimization problem. To address the issue, the authors used the alternating and semi-definite relaxation (SDR) algorithm. Also, to maximize the combined channel gain of each user, a new searching algorithm based on decoding order was proposed. In [278], authors investigated the coherent phase and random discrete phase-shifting designs to improve the performance of IRS-assisted NOMA. In [279], authors have optimized the IRS reflection with discrete phase shifts for the IRS-assisted NOMA and OMA systems to minimize the transmit power of the APs concerning minimum requirements of users. In contrast to [276], [278], and [279], the authors in [280] investigated the sum-rate maximization problem in the IRS-assisted NOMA network for multi-cell scenario. In [277], authors investigated the system performance of IRS-aided NOMA and OMA networks for downlink and uplink transmissions. Numerical results demonstrated that IRS use could significantly enhance system performance, especially improving the diversity order.

2) IRS-MISO-NOMA [281]- [282]

In [281], a MISO-IRS-NOMA transmission model with a fixed decoding order was studied. Assuming ideal beamforming, the phase shift was optimized by maximizing the SINR with ZF beamforming. Under the finite-resolution beamforming assumption, a low-cost implementation structure was proposed to control phase shifts by applying on-off control. In [283], by assuming the perfect SIC decoding order, an effective second-order cone programming (SOCP)-alternating direction method of multipliers (ADMM) based algorithm was proposed for the MISO IRS-NOMA system. To reduce the complexity, a zero-forcing-based suboptimal algorithm was also introduced. In [284], two cases of reflection coefficients design for MISO IRS-NOMA systems were considered. For the ideal IRS scenario, both phase shifts and amplitudes were optimized. For the non-ideal IRS scenario, the amplitudes were fixed, and only the phase shifts were optimized. For both cases, the optimal decoding order was obtained by an exhaustive search. In [285], the power-efficient MISO IRS-NOMA system under quasi-degraded channels was studied. To ensure that the system achieves the capacity region with high probability, an improved quasi-degradation condition was proposed using IRS. Moreover, the beamforming vectors and IRS phase shift matrix were optimized jointly based on the alternating optimization algorithm and the SDR method. In [286], an alternating difference-of-convex (DC) algorithm was proposed to solve the joint beamforming and phase shifts optimization problem. Furthermore, a low-complexity user ordering scheme was proposed by considering the phase shifts and target data rates. In [287], authors proposed the multi-channel downlink communications IRS-NOMA framework, where multiple users were allowed to flexible assigned to the same channel. In [282], the total transmit power minimization problem in the downlink MISO NOMA. IRS-aided system was studied. In this, a penalty-based iterative algorithm was proposed to optimize the passive beamforming vector.

3) IRS-mmWave-NOMA [288]- [289]

In [288], authors integrated IRS with mmWave-NOMA system. The joint active beamforming, passive beamforming, and power allocation optimization were investigated. The non-convex problem was decomposed into sub-problems to address the issue, which were solved by alternative optimization and successive convex approximation. In [289], authors studied the combination of power allocation, phase shifts optimization, and hybrid beamforming design for downlink multiuser RIS-aided mmWave-NOMA. The main goal of this scheme was to maximize the sum-ate of the network concerning phase shifts of the RIS, power allocation at the AP, and the hybrid beamforming.

X. USER PAIRING AND POWER ALLOCATION VARIANTS

1) 2D-NOMA [290]

It consists of both power and code domain NOMA techniques [290]. The power domain NOMA produces multi-level modulation while the code domain generates sparse spreading code words. It was used to reduce the inter-user interference and to increase the Euclidean distance of superimposed signals. To reduce the effect of deep fading, quadrature components of multiple sparse code multiple access (SCMA) code-words were interleaved before the transmission. At the same time, according to the quality of the channels, the window size of interleaving can be adjusted. For this scheme, a mixed-integer optimization technique was formulated to enhance its data rate. The mixed-integer optimization consists of power allocation, power splitting, and codebook assignment. The simulated results show that this scheme outperformed its counterparts in terms of data rate.

2) Ashynchronous NOMA (ANOMA) [291]

In this paper, the authors proposed this scheme to mitigate mutual interference between users by applying different artificial symbol-offset between packets. Also, to simplify the signal detection, a precoding technique at the BS and a whitening-and-decomposing (WD) detection technique along with SIC was applied at the receiver's side. The proposed scheme investigated both the Rayleigh and Gaussian fading distributions. The numerical results showed that ANOMA outperformed synchronous NOMA (SNOMA).

3) NOMA CAP [292]

The authors in this integrated NOMA with multiband carrier less amplitude-phase modulation (multiCAP) scheme to improve the network capacity. The scheme's objective was to provide the dynamic resource allocation to fulfill the data rate requirements of users in an ultra-dense network. The authors experimentally demonstrated that the proposed scheme over a W-band mmWave and fiber system assumes six 1.25GHz multibands and two NOMA levels with quadrature phase-shift keying. The numerical results showed that in a highly dense network, the proposed scheme provides an aggregated transmission rate of 30Gbps.

4) NOMA-multicast (MC) [293]

The authors proposed a scheme to mitigate the problem of content caching, where extra radio resource blocks are occupied with pushing the content objects to the edge devices to optimize the spectrum efficiency. With this scheme, both the multicasting and content pushing phases can be performed simultaneously. Authors in this scheme first studied the single-cell scenario and then extended it to the multi-cell by using stochastic geometry to have an optimal outage probability. Moreover, to enlarge the performance gain of the proposed scheme, they proposed a joint power allocation and content matching design. Also, they proposed two distributed

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optimization algorithms based on the Galey-Shapley matching technique.

5) Virtual pairing (VP)-NOMA [294]

The authors introduced a virtual user pairing scheme. In this scheme, similar channels gain CCUs from a pair with the single CEU to enhance the system's SE. In contrast, to [294], the authors in [295] and [296] also proposed a user pairing scheme on behalf of channel gain difference in between the FUs. They also proposed an even and odd number of FUs in femtocells.

6) TS-NOMA [297]

In [297], the authors proposed a variant of NOMA to investigate a time-sharing (TS) based user pairing strategy to accommodate the similar gain user. This NOMA variant reduces the computational complexity issue of VP-NOMA. With this scheme, one cell center user forms a pair with two or more CEUs in a time-sharing manner. The numerical results showed that it outperformed C-NOMA and OMA concerning ergodic sum capacity.

7) Dynamic Hybrid (DH)-NOMA [298]

It is a dynamic power allocation scheme for hybrid NOMA, applied when channel gain of strong users becomes worst for threshold value for weak users [298]. When this condition occurs, then a conventional OMA scheme is used to serve the users. Otherwise, NOMA is used. The numerical results showed that this scheme provides better trade-offs between two individual user rates than F-NOMA and CR-NOMA. A better outage performance is achieved in comparison to OMA using the outage probability.

8) FAIR-NOMA [299]

It is a fair power allocation scheme applied for two users in a downlink NOMA transmission scenario [299]. The main aim of the scheme was to achieve a guaranteed capacity for users in OMA. Moreover, this scheme does not require any CSI like other NOMA techniques, which results in a high-performance gain. The numerical results showed that FAIR-NOMA enhanced the sum capacity of users' network and capacity compared to the OMA.

9) Distributed base station (DBS)-NOMA [300]

It is a distributed power allocation scheme designed to minimize the total power transmission in each cell by using various resource allocation techniques [300]. Unlike the other NOMA techniques, in this scheme, the SIC decoding technique is applied at both paired UE sides. Moreover, the authors also proposed a mutual SIC technique with suboptimal power adjustment to provide better trade-offs between complexities and transmit power.

10) Wavelet NOMA (W-NOMA) [301]

The authors integrated NOMA with wavelet OFDM. They proposed this scheme to mitigate the interference, improve the bandwidth, and enhance the MU capacity. Also, they proposed a dual PHY layer transceiver for WOFDM based pulse shaping methods to reduce the latency. The performance of the scheme was analyzed using BER. The numerical results showed that the proposed scheme is compatible with 4G networks and provides improved robustness, higher SE, and lower PAPR compared to the conventional NOMA but at the cost of increased hardware complexity.

11) Contention-based NOMA [302]

Contention based uplink (CB-UL) access is an effective technique that was designed to reduce the access latency and uplink access signaling overhead as compared to the conventional dedicated scheduling request (DSR) technique. This technique is effective under low traffic load, but it was found that when traffic load increases, then the performance of this technique is degraded due to an increase in collisions. To overcome this issue, the authors in [302] integrated NOMA with contention based uplink transmissions. NOMA with CB UL reduces the bad collisions and enables the good collisions without knowing which UEs will conduct the CB UL transmissions. In this way, NOMA enhances the performance of the CB UL transmission and reduces the latency. Moreover, the authors also proposed two effective algorithms for user pairing between the downlink SNR information at UE and scheduling information at evolved-Node-B (eNodeB). The numerical results showed that this scheme reduces the latency and improves the SE network.

Y. PHYSICAL LAYER SECURITY

Due to the broadcast nature of the transmitting signal, wireless communication is vulnerable to be eavesdropped [303]. Generally, the security of the transmitted signal is the responsibility of the upper layer by using cryptographic algorithms. This technique provides high security due to encryption and decryption keys, but they are time-consuming and complex [304]. To overcome the issue of the ciphering system, the physical layer security (PLS) has drawn much attention as it provides an alternative method to ensure the security of the physical layer. Jamming, beamforming, cooperative relaying, and proper resource allocation reduce the problem of eavesdropper and improve the physical layer security of the wireless channel.

1) ANFDR-NOMA [305], [306]

In [305], authors studied the optimal power allocation between the information and the artificial noise (AN) signal to maximize the capacity of the two end-to-end channel. Numerical results showed that the NOMA-ANFDR scheme significantly outperformed the NOMA-ANHDR scheme and NOMA-HDR scheme in terms of minimum secrecy outage probability (SOP) and throughout. In [306], authors investigated the secrecy outage performance for a large-scale downlink system with FD-NOMA transmission aided by AN. In this system, legitimate users were randomly distributed according to the homogeneous Poisson point process. To achieve the target, the authors introduced a secure cooperative communication scheme, where nearby NOMA users are operating in FD mode act as jammers and generate AN to enhance the PLS of legitimate transmission.

2) AN-MISO-NOMA [307]

In this, authors studied secrecy beamforming (SBF) scheme for MISO-NOMA systems. Here, SBF scheme efficiently exploits AN to protect the confidential information of two NOMA-assisted legitimate users, such that only the eavesdropper's channel is degraded. Simulation results showed that the proposed SBF scheme achieved an improved SOP and secrecy diversity order.

3) AN-MIMO-NOMA [308]

In [308], an AN-aided scheme was proposed to improve secrecy rate in massive MIMO-NOMA networks. The results revealed that with a sufficiently large number of transmit antennas at the BS, only the illegitimate side was affected by the AN. Also, when the transmit power at the BS was high, the secrecy performance of a user was independent of the inter-cluster interference and AN. It was determined by the uplink training process, which depends on the number of users in a cluster, the uplink transmits power, and the large-scale fading. The results showed the proposed scheme achieved a better secrecy performance at each user and cluster.

4) Cooperative-Dual-Hop NOMA [309]

In this, authors investigated the reliability and security of cooperative dual-hop NOMA for IoT networks, in which the transceivers consider a detrimental factor of in-phase and quadrature-phase imbalance (IQI). The communication between the source and destination is accomplished through a DF relay in the presence of an eavesdropper. Numerical results demonstrated that the existence of IQI usually increased the OP and reduced the IP, which in turn improves the security.

5) NOMA-HB-AN [310]

In this, authors developed a beamforming design with the optimal power allocation to enhance the physical layer security of a NOMA system. The authors used two governing factors to calculate the beamforming vector, balancing the SNR or SINR between the weak and strong users in the considered NOMA system. Also, to demonstrate the benefits of the proposed beamforming design, the optimal power allocation among information and AN signals by focusing on the asymptotic scenario with many transmit antennas is calculated. Also, the authors proposed an efficient solution to the optimization of power allocation coefficients and the governing factors in the high SNR regime, which is shown as a generic and near-optimal strategy.

6) Jamming-Aided-NOMA [311]- [312]

In [311], authors studied the cooperative jamming in the UL NOMA system in the presence of one eavesdropper to improve the security of the system. The performance of the system was analyzed in terms of secrecy rate probability, secrecy outage probability, and effective secrecy throughput. In contrast to [311], the authors in [312] studied the friendly EH jammer aided uplink NOMA transmission and proposed the random EH jammer selection (REJS), maximal EH jammer selection (MEJS), and optimal EH jammer selection (OEJS) schemes to enhance the PLS of the NOMA system. Based on the proposed transmission schemes, the performance of the schemes was analyzed in terms of connection outage probability (COP), secrecy outage probability (SOP), and effective secrecy throughput (EST) to examine the reliability and security of the system.

Z. UPLINK NOMA

In an uplink NOMA [313], the SC is used at the users' side to multiplex the power signals. After multiplexing, the signals are transmitted over the same frequency channel. On the other side, a SIC technique is used at the BS to demultiplex the required signal. Hence, the user's signal with the highest channel gain or near the BS is decoded first, and the user's signal with the lowest channel gain or far from the BS is decoded in the last. The SIC technique reduces the intra-user interference received from high power signals to decode the signal. The variants of Uplink NOMA are as follows:

1) HMA [314]

In this, the authors investigated an EE resource allocation for an uplink hybrid system, where NOMA is integrated into OMA. To ensure the quality of service for the users, a minimum rate requirement is predefined for each user. The EE maximization problem is formulated concerning the user clustering, channel assignment, and power allocation (PA) to achieve the goal. To solve this problem, firstly, a many-to-one bipartite graph is used between the users and RBs. The swap matching is applied to solve the joint user-RB association and PA scheme, which converges within a limited number of iterations. Afterward, to solve the problem of PA, a low-complexity algorithm is proposed. Numerical results showed that the proposed HMA scheme outperformed the OMA-hybrid scheme.

2) E-NOMA [315]

In this, the authors investigated the EE maximization problem for Uplink mmWave mMIMO-NOMA. A hybrid analog-digital beamforming scheme was first proposed to lower the number of RF chains at the BS. Then, an iterative algorithm was introduced to allocate the power for EE maximization. Also, to remove the inter-cluster interference at the BS, an enhanced NOMA scheme was presented. Simulation results showed that the proposed scheme achieved higher EE than OMA.

3) SGF-NOMA [316]

In this, authors studied an adaptive power allocation (APA) strategy for an uplink NOMA with semi-grant-free (SGF) transmission. In this, one grant-based user (GBU) shares the same resource with other grant-free users (GFUs) using the grant-based scheme and grant-free schemes, respectively. The proposed strategy is based on the fact that the quality of service for the GBU can be strictly guaranteed if its instantaneous data rate is larger than the target date rate. Simulated results showed that the proposed scheme reduced the OP and improved the full diversity gain for the GFUs.

4) MC-NOMA [317]

In this, the authors studied the resource allocation for a multi-carrier uplink NOMA system. Unlike existing works on multi-carrier uplink NOMA, authors considered a scenario where the number of subcarriers allocated to a single user is not constrained. The main aim is to maximize the system's sum-rate concerning the sub-carriers and transmission power. To achieve the target, the authors proposed a low-complexity iterative water-filling algorithm. Also, to improve the EE of the network, the authors proposed the power optimization scheme. Results showed that the proposed schemes acquire better results as compared to the benchmark NOMA and OMA schemes.

5) RF-FSO-NOMA [318]

In this, authors studied a relay-assisted uplink NOMA system. In this system, two RF users are grouped for simultaneous transmissions over each resource block to an intermediate relay. The relay then forwards the amplified version of the users' aggregated signals, in the presence of multiuser interference, to a relatively far destination. A high throughput free-space optics (FSO) link was employed at the relay-destination backhaul link to cope with the users' ever-increasing desire for higher data rates. It was assumed that the FSO backhaul link was subject to Gamma-Gamma turbulence with pointing error. Also, a Rayleigh fading model was used for the user-relay access links. Under these assumptions, the authors derived the closed-form expressions in terms of outage probability and ergodic capacity.

AA. ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING

Machine learning (ML) is an application of artificial intelligence (AI) that provides systems the ability to learn and improve from experience without being explicitly programmed automatically. Machine learning focuses on developing computer programs that can access data and use it to learn for themselves. ML algorithms for resource optimization problems have certain advantages over traditional optimization techniques. Primarily, optimization approaches suffer from high cost and complexity when the number of parameters configured becomes large. Optimization algorithms are often sensitive to parameter selection, and heuristics have to be re-run from scratch every time there is a small change in the system model. All these limitations of the traditional optimization tools have motivated researchers to explore the use of ML techniques for resource optimization in communications systems [319]. Additionally, when multi-objective optimization problems are framed, the goal is to find Pareto-optimal solutions, i.e., a solution space where the improvement of one metric necessarily degrades some other metric. Due to the large search space involved, ML is an attractive solution for finding such Pareto-optimal solutions [319].

1) Unsupervised Learning (UL)-NOMA [320]

In [320], authors studied the combination of power allocation and user clustering algorithms over mmWave-NOMA networks. The paper's main aim was to maximize the sum rate of mmWave-NOMA concerning power and users' QoS. To achieve the goal, the authors used the K-means-based online user clustering employing the ML technique. Next, to optimize the power across each cluster, the beamforming matrix technique was used. Numerical results revealed that the proposed scheme improved the sum rate of the network as compared to state-of-art schemes.

2) FL-NOMA [321]

In this, the authors integrated the NOMA with federated learning (FL) to reduce the aggregation latency. Here, the authors investigated the performance of FL update at mobile edge devices connected to the parameter server (PS) with wireless links. Considering the spectrum limitation on the wireless fading channels, we further exploit non-orthogonal multiple access (NOMA) together with adaptive gradient quantization and sparsification to facilitate efficient uplink FL updates. Simulated results show that the proposed scheme achieved lower latency as compared to TDMA.

3) DL-NOMA [322]- [323]

In [322], authors proposed an effective DL-aided NOMA scheme, in which several NOMA users with random deployment are served by one BS. Here, the long short-term memory (LSTM) is first trained by simulated data under different channel conditions via offline learning. Then the corresponding output data can be obtained based on the current input data used during the online learning process. In contrast to [322], authors in [323] integrate DL with NOMA to tackle the challenge of establishing ultra-responsive and ultra-reliable connectivities for massive devices in Tactile IoT.

4) DRL-NOMA [324]- [325]

In [324], authors proposed a DRL-based resource allocation scheme to maximize the performance of the multi-carrier NOMA system in a downlink scenario. The authors' main aim was to maximize the sum rate of the network concerning channel and power allocation constrained. To address the channel assignment, the authors used the attention-based neural network exploiting an encoder-decoder structure. On the other side, to optimize the power, a square root-based mathematical technique is used. Numerical results showed that the proposed scheme achieved higher performance than the state-of-art schemes. In contrast to [324], authors in

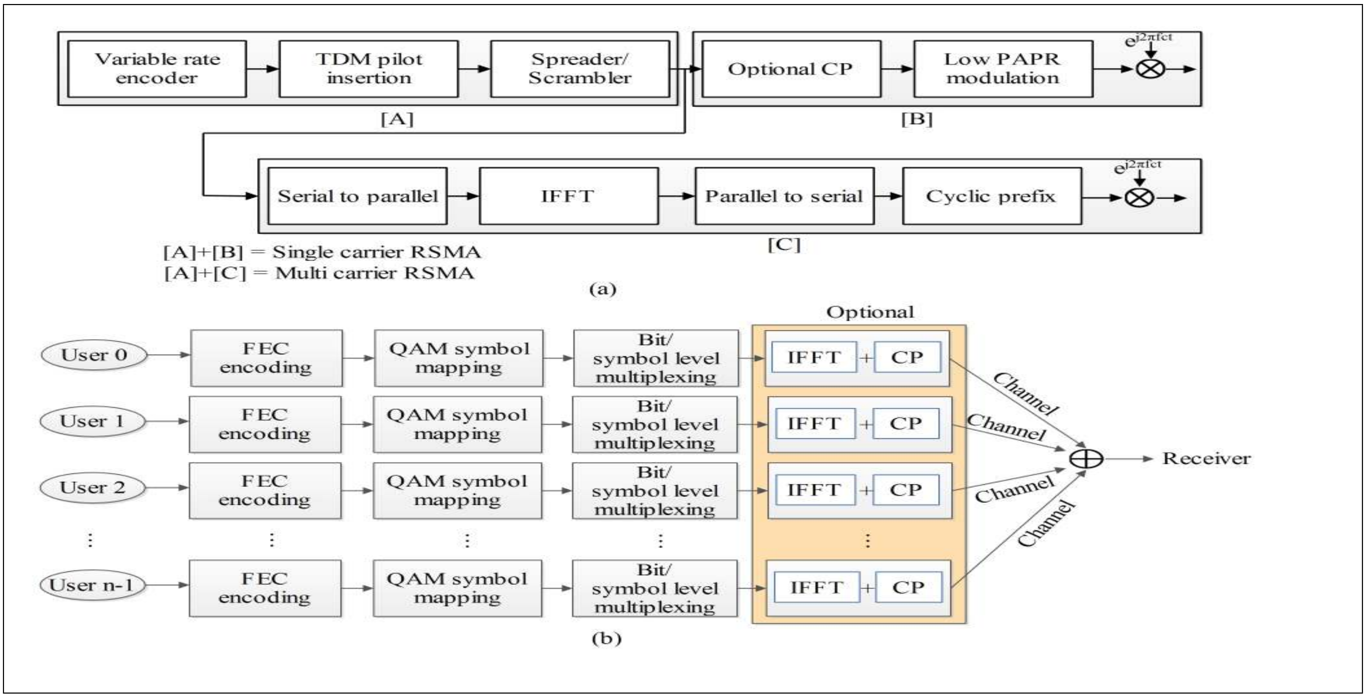

FIGURE 25: Block diagram of (a) Resource spread multiple access (RSMA), and (b) Low code rate and signature-based shared access (LSSA)

[325], authors applied the DRL in the decision making for grant-free NOMA systems to mitigate collisions and improve the system throughput in an unknown network environment.

IV. CODE DOMAIN NOMA (CD-NOMA)

CD-NOMA is a technique in which user-specific spreading sequences multiplex the signals at the transmitter side. The main advantages of this technique are (i) low-density, (ii) low inter-correlation, and (iii) support grant free access. CD-NOMA is an advanced version of CDMA, which was proposed in the '90s. With respect to CDMA, CD-NOMA receivers have to detect the active codes of the receivers and have to estimate their data. In CD-NOMA, compressive sensing (CS), Gaussian random, and sparse codes are the backbone of this technique. It has five variants: (i) Scrambling-based NOMA, (ii) Interleaving-based NOMA, (iii) Spreading-based NOMA, (iv) Coding-based NOMA, and (v) Lattice and Beam based NOMA. The detailed description of each variant is shown in Fig. 26 and discussed in the following subsections.

A. SCRAMBLING BASED NOMA

Scrambling based NOMA has types: Low code rate and signature-based shared access (LSSA) and Resource spread multiple access (RSMA). RSMA was designed by Qualcomm, whereas LSSA was designed by ETRI. The block diagrams of RSMA and LSSA are shown in Fig. 25. In these schemes, different scrambling structures and low rate channel coding are used for each user. Both are long sequence and bit-level based NOMA, respectively. In RSMA, the long sequence of user signature is used, resulting in high latency and decoding complexity at the receiver side. These issues can be resolved using the LSSA scheme, where the length of the user signature is reduced. To separate the user's signatures at the receiver side, the elementary signal estimator (ESE) and minimum mean square error with successive interference cancellation (MMSE-SIC) were used [326]. The detailed description of RSMA and LSSA is as follows:

1) Resource spread multiple access

It uses a long spreading or scrambling sequence, where sequences of each user are broadcasted in the form of signals over the available bandwidth. As a result, full diversity and low forward-error-correction (FEC) is achieved. To separate the signals of different users at the receiver side, different scrambling or sequences are used. In this scheme, every user transmits their data at any time. To reduce the multi-user interference (MUI), scramblers can be replaced by different interleaves. As per the requirements of applications, it is categorized into two types: single carrier (SC), and multi-carrier (MC) RSMA [327] each of which is described as follows:

(a) *Single carrier resource spread multiple access:* It is suitable for the uplink scenario to reduce the peak-to-average-power ratio (PAPR). In this technique, a single carrier modulation is used to extend transmitting data coverage and reduce the UEs battery power consumption. To separate the signals of SC-RSMA, the matched filter is used

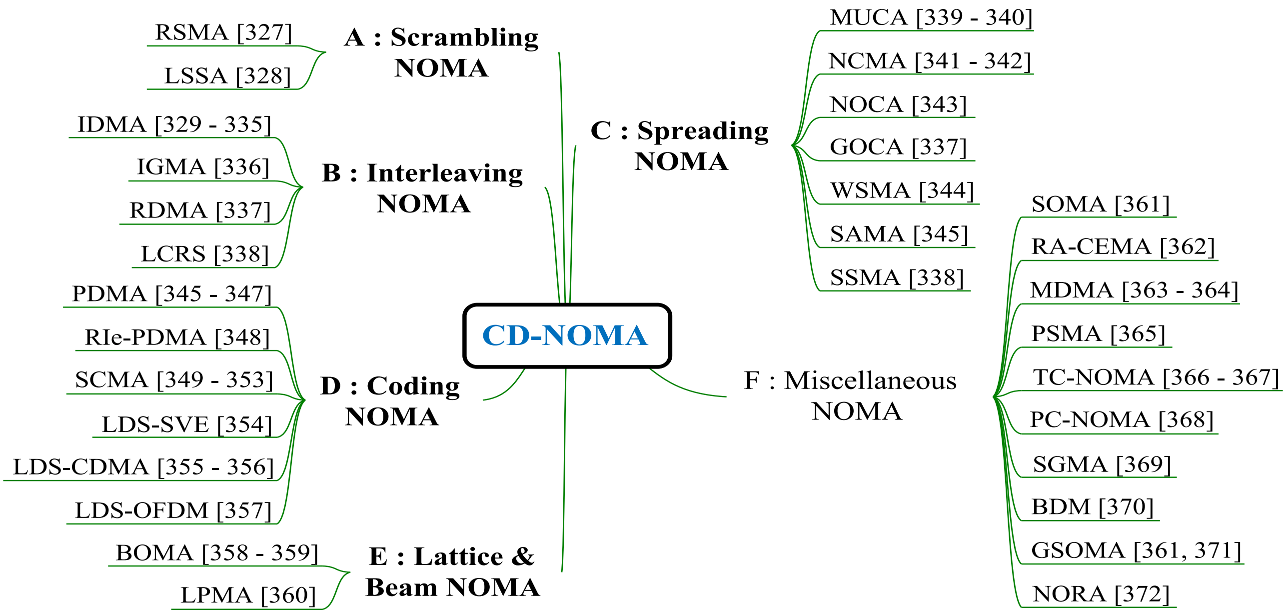

FIGURE 26: Detailed taxonomy of Code domain NOMA variants

at the receiver side. Moreover, it supports grant-free and asynchronous transmission to reduce the signalling overhead because it does not depend upon joint detection and synchronization requirements.

(b) *Multi carrier resource spread multiple access:* It is suitable for the downlink scenario and is used to reduce the complexity of the receiver. This technique is split into multiple layers (virtual layers) for each user, reducing the latency and increasing the SE. Its complexity is higher than SC-RSMA.

2) Low code rate and signature-based shared access

It is suitable for asynchronous uplink transmission [328], where a low rate channel encoder encodes each user's signal. Then, the user-specific signature is multiplexed with the output of the channel encoder to mitigate the MUI. The vector length of each user signature pattern is the same and should be unknown to other users to achieve it. In this technique, the BS separates the signals of different users by correlating them with the user's specific signature patterns even though the transmission time for each user is different. Moreover, it supports multi-carrier variants to fully exploit the frequency diversity, resulting in a large bandwidth and lower latency.

B. INTERLEAVING-BASED NOMA

It consists of four types of NOMA schemes, interleave division multiple access (IDMA), interleave-grid multiple access (IGMA), repetition division multiple access (RDMA), and low code rate spreading (LCRS). Samsung designs IGMA, IDMA by Nokia, RDMA by Mediatek, and LCRS by Intel, respectively. Common features of these schemes are (i) different channel inter leavers are used for overlapped multiple users, and (ii) a low-rate channel coding for multiuser decoding. A detailed description of these schemes is as follows.

1) Interleave division multiple access

In this scheme, user's signals are separated from each other by using different interleaving patterns. The structure of IDMA is as shown in Fig. 27. This scheme was first investigated by Li *et al.* [329] to improve the performance of asynchronous CDMA. Similar to CDMA, it also reduces the effect of fading and ICI. In comparison to CDMA, it achieved a $\frac{E_b}{N_o}$ gain of 1dB at a BER of 10^{-3} in highly loaded systems having a normalized user-load of 200% [330]. In contrast to [329], the authors in [331] explored more features of IDMA such as EE, frequency diversity, and rate adaption. In [332], the authors investigated that the IDMA achieved the capacity equaled to Gaussian MAC when an iterative decoding strategy was used with an interleaved low-rate codes. In [333], the authors proposed a user-specific interleaver designed to solve the problem of memory cost and reduces the signalling overhead between the BS and users. In [334], the authors explored additional features like robustness and user overload tolerance. Moreover, the authors in [335], discussed the concept of IDMA in both single path and multipath fading channels, which provides a large diversity gain as compared to the bit-interleaving scheme.

2) Interleave-grid multiple access

The structure of IGMA is as shown in Fig. 27, where at the transmitter side, bit-level repetition, channel encoding, zero-padding, modulation, bit-level interleaving, and symbol level

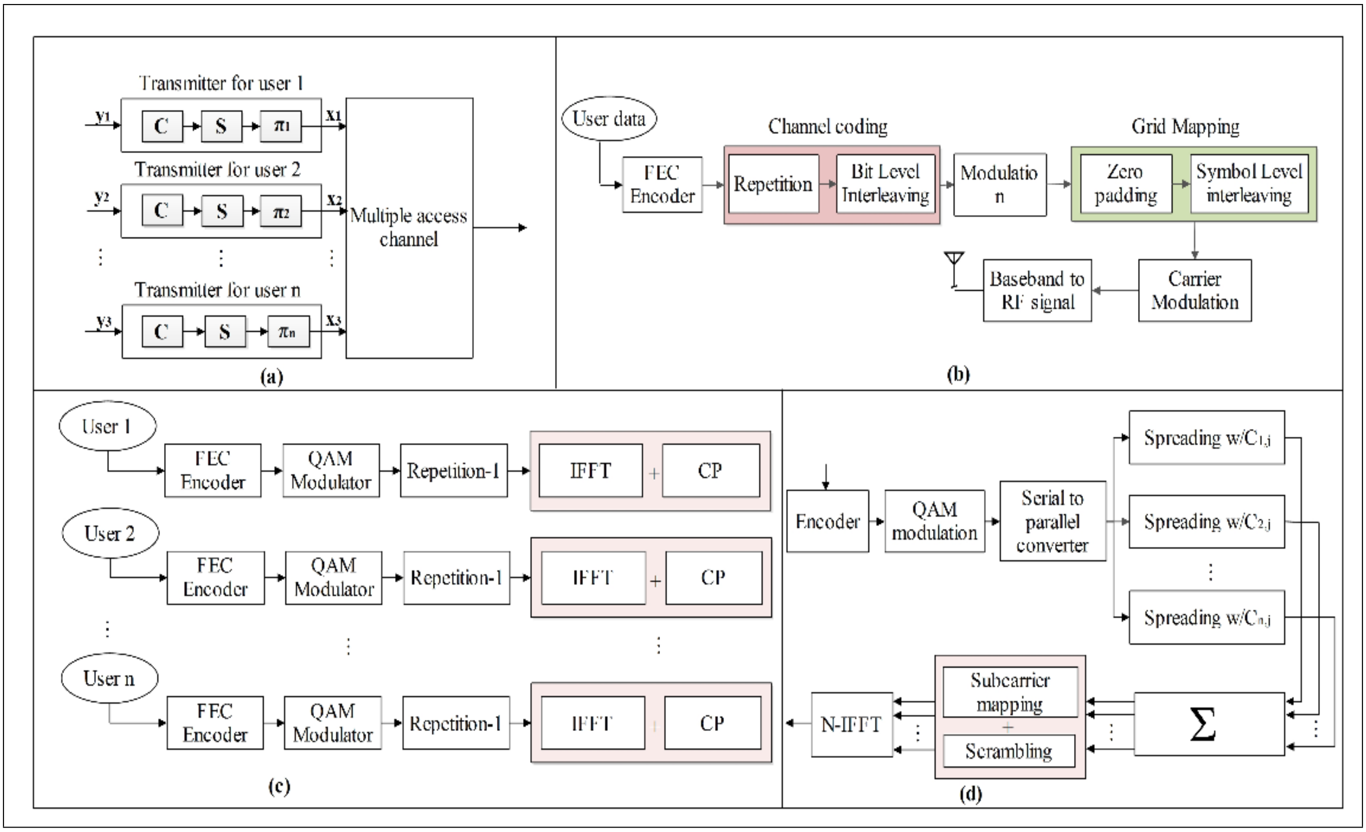

FIGURE 27: Interleaving-based NOMA schemes for (a) IDMA, (b) IGMA, (c) RDMA, and (d) LCRS

interleaving are used sequentially by each user. In this technique, sparse grid mapping patterns, bit-level interleavers, and the mixture of both were used to separate the signals streams of various users. Bit-level interleavers/grid mapping patterns support different connection density patterns. It creates a trade-off between sparse resource mapping and the channel coding gain. The presence of sparse grid mapping patterns reduces the detection complexity and symbol-level collisions concerning IDMA [336]. Finally, the symbol level interleaving in IGMA randomizes the symbol sequence order, which helps combat the frequency selectivity and ICI.

3) Repetition division multiple access

It is a special type of cyclic interleaving scheme [337] in which the symbol-level interleaving scheme is used instead of bit-level interleaving. In this scheme, different user signals are distinguished by using a cyclic-shift repetition pattern, which provides a complete randomized MUI and time and frequency diversities. The transmission structure of IDMA is as shown Fig. 27. Its structure is simpler than IDMA and RSMA, and it provides low signalling overhead due to the absence of user-specific scrambling and interleaving patterns. Moreover, a SIC technique is employed at the receiver side to separate each user's data from the superimposed signal.

4) Low code rate spreading

In this scheme, data bits are transmitted over the entire non-orthogonal transmission area by using low-rate coding and bit-level repetition [338]. It provides the maximum coding gain, where MMSE-SIC is used at the receiver side to detect the multiuser signal [329].

C. SPREADING-BASED NOMA

Spreading-based NOMA is categorized into seven different types such as multi-user shared access (MUSA), non-orthogonal coded multiple access (NCMA), non-orthogonal coded access (NOCA), group orthogonal coded access (GOCA), welch-bound spreading multiple access (WSMA), successive interference cancellation amenable access (SAMA), and sequence spreading multiple access (SSMA). The detailed description of all these techniques is described as follows.

1) MUSA

It supports low cross correlation-based short complex spreading sequences such as spreading sequences that are non-sparse to reduce the interferences. An example of MUSA with its complex sequences is shown in Fig. 28 (a). At the transmitter side, after encoding and modulation, the modulated symbols of each user are spread by using the property of complex sequences $\{-1, 0, +1\}$. Then, these spreading

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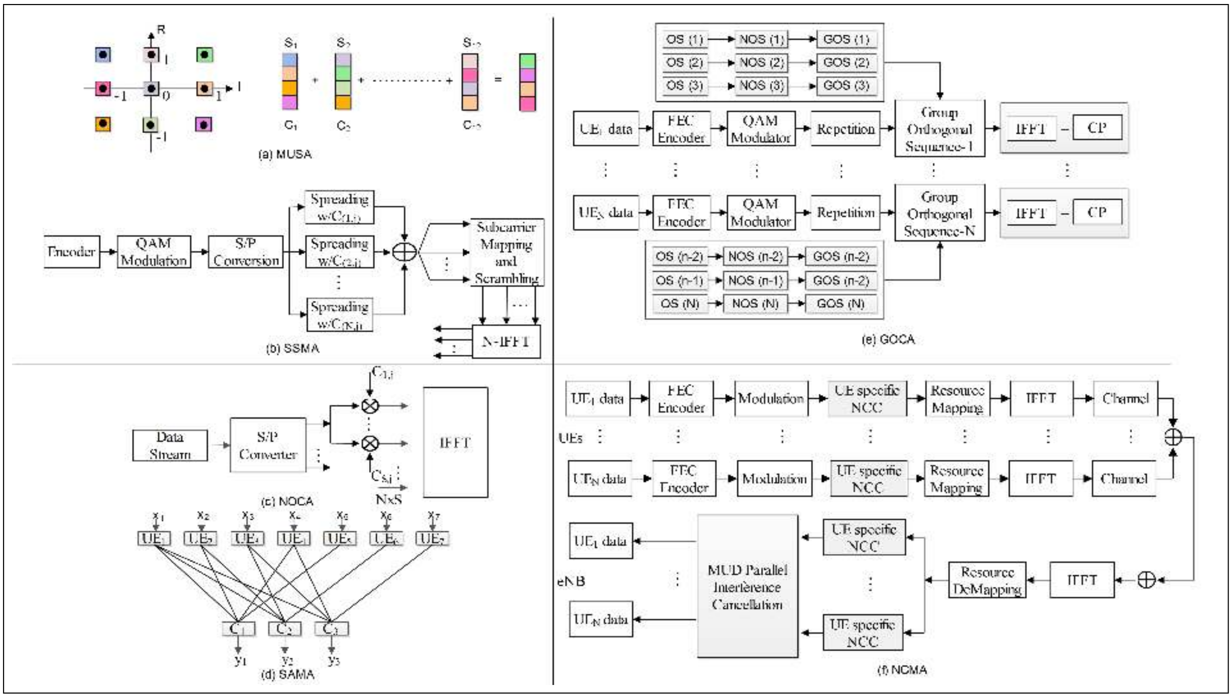

FIGURE 28: Structure of: (a) MUSA, (b) SSMA, (c) NOCA, (d) SAMA, (e) GOCA, and (f) NCMA

sequences are passed through the same radio resources. On the other hand, at the receiver side, SIC is used, which separates the superimposed multi-user signals [339], [340]. In this scheme, each user randomly selects one spreading sequence from a sequence pool consists of multiple spreading sequences. Then, each user uses a different spreading sequence for different symbols to mitigate the average MUI and enhance the system's performance level. The advantages of MUSA are as follows (i) suitable for mMTC because it supports grant-free transmission, (ii) Fewer collisions due to same spreading sequences, (iii) User detection can be carried out without the knowledge of spreading code, and (iv) It can handle 700% user overload on multipath fading channel due to high-frequency diversity.

2) NCMA

It uses dense spreading sequences similar to MUSA, but its main goal was to minimize the MUI and to handle the high overloading capacity [341]. In this technique, spreading sequences are obtained by solving the Grassmannian line packing problem to maximize the minimum chordal distance between spreading codes. The spreading sequences of NCMA are known as non-orthogonal cover codes (NCC), which are found to be suitable to predict the interference level [342]. The structure of NCMA is as shown in Fig. 28 (f). At the transmitter side, the modulated symbols are spread by using the NCC. Also, to reduce the PAPR, an additional FFT operation is performed before the IFFT. On the other hand, a PIC detector is used to decode the superimposed signals at the receiver's side. Advantages of NCMA are: (i) Improved throughput and (ii) enhanced connectivity with a small loss of block error rate (BLER).

3) NOCA

It used the property of low cross-correlation, which operates in both time and frequency domain. In this scheme, before transmitting a sequence, its modulated symbols are spread according to the non-orthogonal sequences [343]. Its spreading sequences are the reference signals defined in LTE, generated by the cyclic shifts of a bases sequence. The minimum spreading factor of NOCA is taken as 6. In this technique, a modulated symbol is converted into a parallel subsequence using an S/P converter. Then, each subsequence is spread by non-orthogonal sequences and then mapped onto different sub-carriers. Then, the minimum mean square error with parallel interference cancellation (MMSE-PIC) is used to separate each user's signal at the receiver side. It is used to mitigate the inter-cell interference because it supports many spreading sequences and can also handle high overload easily, as shown in Fig. 28(c).

4) GOCA

It is an updated version of RDMA [337], in which modulated symbols are spread using a group of orthogonal sequences into shared time and frequency resources after repetitions. The structure of GOCA is as shown in Fig. 28 (e). Moreover, it uses a two-stage method to produce grouped orthogonal sequences used in the first stage, whereas non-orthogonal sequences in the second stage. Its spreading sequences are suitable for a group of multiple users. It uses an MMSE-SIC to decode the user's signal.

5) WSMA

Its spreading sequence was based on Welch bound, which reduces the cross-correlation of spreading sequences [344]. In this technique, the MMSE-SIC technique is used at the receiver side to decode the user's signals. Moreover, its spreading sequence has a low cross-correlation as compared to the spreading sequences of MUSA.

6) SAMA

This scheme is a combination of signature matrix and SIC based iterative message-passing algorithm [345]. The structure of SAMA is as shown in Fig. 28 (d). In this technique, the symbols of each user are designed based on their diversity orders in the frequency domain. The SIC-based iterative message-passing algorithm eliminates the MUI and enhances the diversity gain and transmission rate for multi-users. Let us consider an uplink scenario consists of N users and J orthogonal OFDM subchannels. Its model is based on MUSA, but in SAMA, spreading sequences for users are equal to one. The spreading matrix in SAMA is represented as $S = \{s_1, s_2, .s_N$. The advantages SAMA matrix are i) maximizes those number of groups which are having a different number of $1's$ in their spreading sequences, and ii) it minimizes the number of the overlapped spreading sequences which are having the same number of $1's$ in their sequences. The number of users based on N orthogonal subchannels is given as follows.

$$\binom{J}{1} + \binom{J}{2} + .. + \binom{J}{J} = 2^J - 1. \quad (14)$$

If J=2 and K=3, then spreading matrix can be calculated as follows:

$$S_{2,3} = \begin{bmatrix} 1 & 1 & 0 \\ 1 & 0 & 1 \end{bmatrix} \quad (15)$$

7) SSMA

It is a short sequence spreading multiple access technique which directly spreads the modulated symbols with multiple orthogonal codes. Then, it transmits the spread symbols in time-frequency resources allocation for non-orthogonal transmission [338]. Its structure is as shown in Fig. 28 (b). It behaves like NOCA when the user-specific sequences are used to decrease the MUI.

D. CODING-BASED NOMA

It consists of PDMA, SCMA, and LDS-SVE, which CATT, Huawei, and Fujitsu design. The transceiver block diagrams of these schemes are shown in the structure of GOCA is shown in Fig. 29. It is used to design a sparse codebook overlapped in the multiple (space, code, time, or frequency) domains. In all these schemes, a message-passing algorithm (MPA) was used at the receiver side for MUD. These schemes have high complexity, which varies exponentially with the size of the codebook. To reduce the complexity from exponential to linear, a novel expectation propagation algorithm (EPA) was proposed in [50]. This algorithm is based on an approximate interference method and was mostly used in the machine and deep learning era.

1) PDMA

It is an MC-NOMA scheme based on SAMA technique [345]. This technique utilizes the multiple domains' resources consisting of power/code/spatial or their combinations. In this technique, user signals can be multiplexed into different subcarriers, which increases the number of accessed users. It supports unequal diversity at the transmitter side but equal diversity at the receiver side. In PDMA, at the transmitter side, non-orthogonal patterns maximize the diversity to minimize the correlations among the users. SIC is used to decode the irregular sparse signatures [346]. An example of PDMA, which consists of six users and four subcarriers, is shown as follows:

$$G_{PDMA} = \begin{bmatrix} 1 & 1 & 1 & 0 & 0 & 0 \\ 1 & 1 & 0 & 1 & 0 & 0 \\ 1 & 1 & 1 & 0 & 1 & 0 \\ 1 & 0 & 0 & 1 & 0 & 1 \end{bmatrix} \quad (16)$$

Where 1 represents that users occupy the subcarrier. PDMA cannot ensure strict sparsity constraints. In downlink PDMA, the signal received at the i^{th} user through all the subcarriers is represented by follows:

$$y_i = diag(g_i) G_{PDMA} x + n_i. \quad (17)$$

In uplink NOMA, the signal received at the b^{th} BS is represented as follows:

$$y_b = (g_b \odot G_{PDMA}) x + n_b, \quad (18)$$

where $x = [x_1, x_2, x_3, ..., x_I]^T$, n=$[n_1, n_2, n_3, ..., n_I]$ represents the noise and g_i and g_b represents the channel gain between the BS and i^{th} user and channel gain between the all the users and uplink, respectively. The numerical results of [347] show that PDMA in an uplink and downlink scenario achieved a normalized throughput of 200% and 50%, respectively as compared to LTE.

2) RIePDMA

It is a random interleaved enhanced PDMA scheme used to provide the massive connectivity [348]. It is designed by inserting interleavers between the PDMA encoder and the channel encoder. The random interleaver in RIePDMA reduces the two effects of a channel: (i) fading effect and (ii) interference-effect. During the mitigation, RIePDMA does not disturb the order of encoded bits. It enhances the performance of the network as compared to PDMA to support massive connectivity.

3) SCMA

It was proposed by Nikopur *et al.* [349] to decrease the complexity of receiver and to improve the reliability in

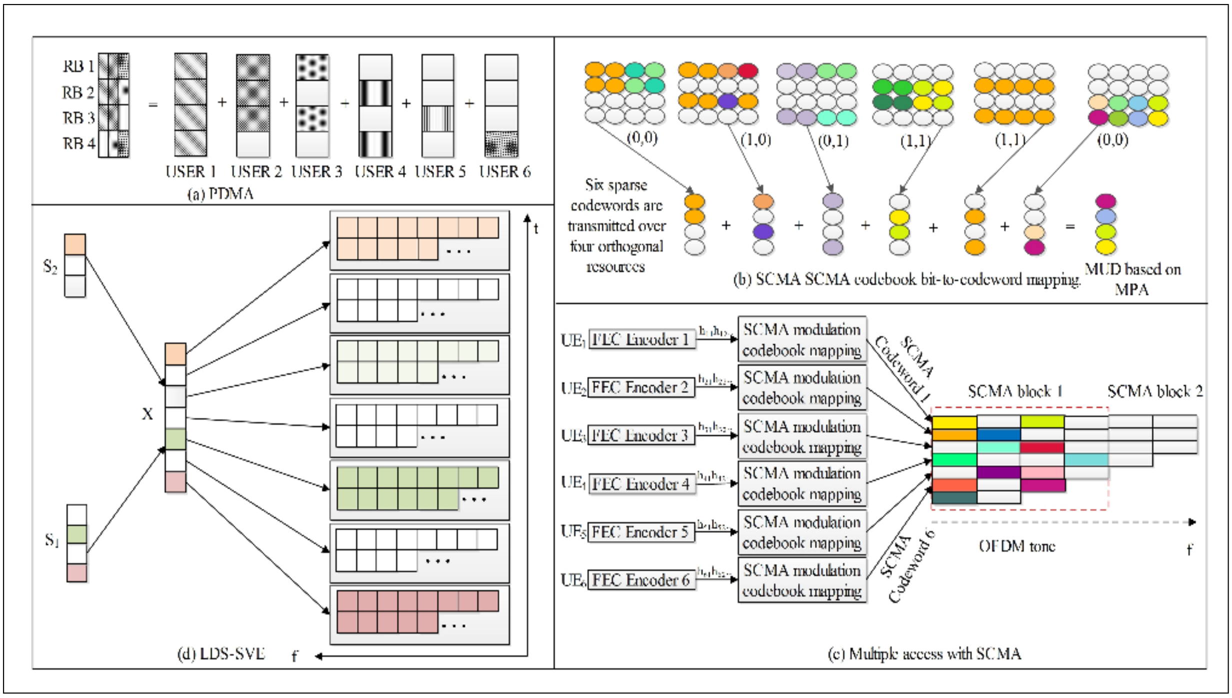

FIGURE 29: Transceiver block diagram for (a) PDMA (b) Bit-to-codeword mapping in SCMA (c) Multiple access with SCMA, and (d) LDS-SVE.

high overhead conditions [350] [351]. It uses the coded bits to multidimensional modulation symbols, as per predefined sparse codebook [352], rather than sequentially conducting modulation and low-density spreading. The authors in [353] proposed that to perform multiplexing in SCMA, both the multidimensional constellation and resource element mapping are essential. The transmission process of SCMA is shown in Fig. 29 (b). In [352], the authors proposed a new codebook design for SCMA based on rotation, shuffling, and permutation. The SCMA also provides a large performance gain by allowing the pairing among symbols located in multiple radio resources, as shown in Fig. 29 (b). In this scheme, the message passing algorithm (MPA) is used at the receiver side to detects the multiple data streams in the form of symbol-level. The example of the SCMA matrix is given as follows:

$$G_{SCMA} = \begin{bmatrix} 1 & 1 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 1 & 1 & 0 \\ 0 & 1 & 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 \end{bmatrix} \tag{19}$$

In SCMA, at the receiver side, MPA enlarges the computational burden when the number of multiplexed users is more. To handle the computational complexity of the receiver, two techniques are used i) the sparseness level of SCMA codewords and ii) the use of multidimensional constellations with a low number of projection points per dimension. SCMA is multiple access that promises some significant advantages such as-to support large levels of connectivity, provides reduced transmission latency, and it is also able to provide energy saving. Block diagrams of SCMA with multiple access are shown in Fig. 29 (c).

4) LDS-SVE

It is an extension of LDS. It is designed to produce a large user signature vector [354], where several element signature vectors are transformed and concatenated into a large signature vector. It applies the user signature vector over the RBs to use the time and frequency diversity based on their channel conditions as shown in Fig. 29 (d).

5) LDS-CDMA

It is an advanced version of CDMA and is based on low density parity-check (LDPC) codes [355], [356]. In this scheme, orthogonal variable spreading factor (OVSF) codes are used, whereas, in conventional CDMA, dense spreading sequences are used to eliminate the interference. To achieve the performance equivalent to maximum-likelihood (ML) detection, an MPA is used at the receiver side to demultiplex the signals.

6) LDS-OFDM

It is a mixture of LDS-CDMA and OFDM to support multiple carrier scenarios [357]. Like LDS-CDMA, in this scheme, sparse coding sequences are implemented at the transmitters side and MPA detection at the side of the receiver. In this technique, the data stream mapping consists of two steps. In the first step, data bits are spread by using low-density spreading techniques, and in the second step, each bit of

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data stream is transmitted over different subchannels using an OFDM modulator.

E. LATTICE AND BEAM-BASED NOMA

When the users have similar channel conditions, the performance of NOMA degrades concerning the OMA. To address this problem, researchers proposed the geometrical separation technique in between the users during superposition transmissions. This technique uses beams to form a cluster among the users having different channel conditions. Despite the advantage, this technique does not cope up when the user density and traffic demand increases due to the following reasons: (i) complexity increases, and (ii) co-channel interference arises in between the users of neighboring clusters. To overcome this issue, a new multiple access technique LPMA is introduced. On the other side, BOMA is a technique in which separate tiled building blocks are used for the poor CSI users concerning the good CSI users. In this way, this technique improves the BER performance of poor CSI users.

The detailed description of both these techniques is described as follows.

1) BOMA

It multiplexes the user signals of perfect CSI with the imperfect CSI to improve their capacity, as shown in Fig. 30 (a). In this scheme, the imperfect CSI achieves the BER performance similar to the perfect CSI using a minimum Euclidean distance. In this, the building blocks of perfect CSI users are used to constellate imperfect CSI users to attain a similar BER [358], [359]. In the imperfect CSI user, the constellation point is the center of the building block, and the tiled building block can be treated as interference. Moreover, as the size of the building block gets decreases, the performance to detect the degradation becomes minimum. This scheme is suitable for massive MIMO techniques and high-frequency band signals.

2) LPMA

This scheme was proposed by [360] by considering a non-orthogonal multi-user transmission scheme for the downlink scenario. It is suitable for both PD-NOMA and CD-NOMA to increase their multiplexing gain. Its usage in the power domain scheme enhances the throughput by superimposing different-power streams. In contrast, its usage in the code domain improves the security of codes by using the linear combination of lattice codes. LPMA uses lattice coding at the transmitter side to encode the information of users and SIC at the receiver side to decode the information. In comparison to PD-NOMA, LPMA provides better performance gain concerning the increase in channel quality difference of users. Moreover, it provides high encoding and decoding complexity as compared to CD-NOMA.

a: Comparison of existing NOMA schemes based on cooperative Communication

Table 13 provides the detailed relative comparison of existing variants of CD-NOMA using parameters, transmission type, carrier type, the receiver used, a technique used, and merits and demerits of each variant.

F. MISCELLANEOUS

1) SOMA

In this variant, each user's data rate is independently modulated in a QAM constellation. Then, based on appropriate power allocation coefficients, the data rate is summed up to generate the higher-order QAM modulation, as shown in Fig. 31 (a). This technique was designed to address the uplink capacity shortage problem in mMIMO [361]. The main difference between SOMA and NOMA is the symbol constellations. In NOMA, the post superposition symbol constellation mappings are divided with SIC without gray mapping, whereas in SOMA, it depends upon gray mapping.

2) RA-CEMA

It is used to generate a superimposed symbol. It also transmits the QAM modulation but differs from SOMA because mapping the coded bits of each user is adaptively controlled as per the user's channel condition to enhance and control the system's data rate. The authors in [362] used RA-CEMA to mitigate the problem of amplitude weighted (AW) NOMA, which arises during the transmission for degraded broadcast channel. Using RA-CEMA, the authors applied the multiplexing technique over UEs signals to store their codewords and then map the columns into constellation symbols. The results show that RA-CEMA performs similarly to other conventional schemes based on their superposition coding but overcomes the potential standardized problems that arise due to unconventional constellations.

3) MDMA

Hsiao *et al.* [363] proposed a scheme which combine mmWave technique with mMIMO at the BS. It reduces the multiple access interference (MAI) of cellular mobile radio. It enhances the processing gains of the system by using multiple antennas at the BS, as shown in Fig. 32 (a). The presence of mmWave in this scheme improves the channel bandwidth to provide high data transmission, whereas massive antennas at BS are used to reduce the MAI to improve the system's capacity. In MDMA, users are separated from each other by their distinct multipath structures. Moreover, the authors in [364] explored the feasibility and applications of MDMA.

4) PSMA

It was proposed by Moltafet [365] to improve the network SE. The authors used a combination of PD and CD NOMA to transmit the multiple signals over a subcarrier simultaneously. In this scheme, PD-NOMA was used to send the signals to users via different power levels, and SCMA was

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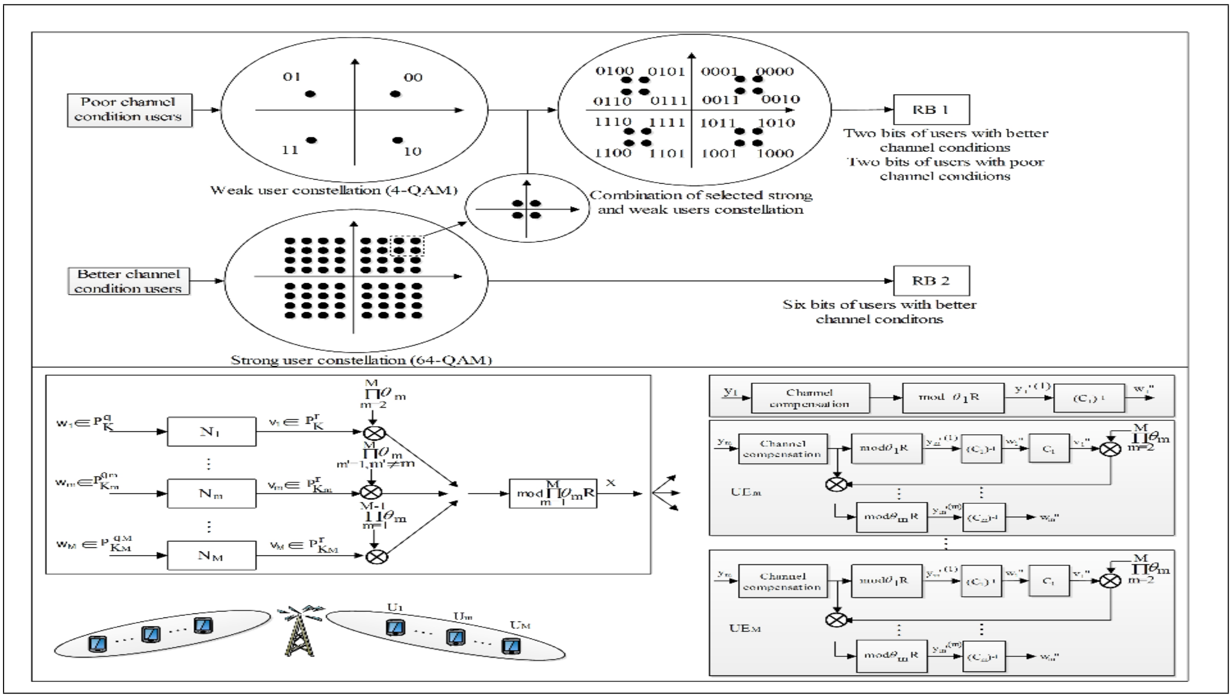

FIGURE 30: Block diagram of Lattice and Beam-based NOMA for (a) BOMA, and (b) LPMA

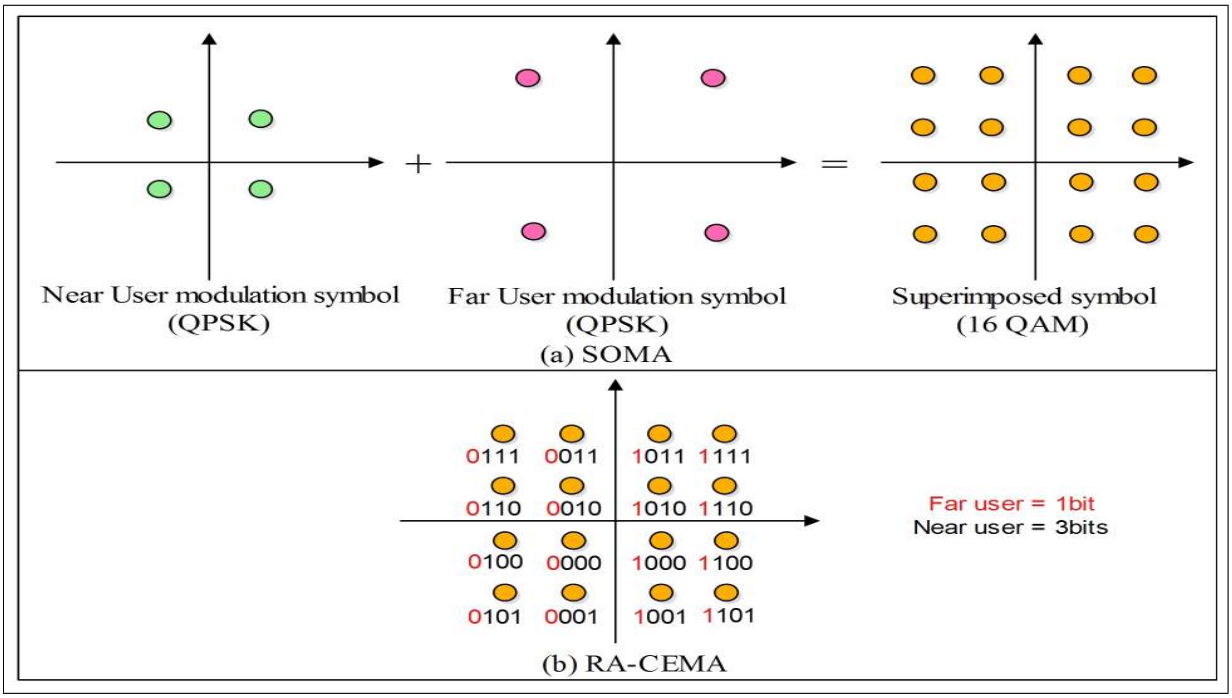

FIGURE 31: Block diagram of (a) SOMA, and (b) RA-CEMA

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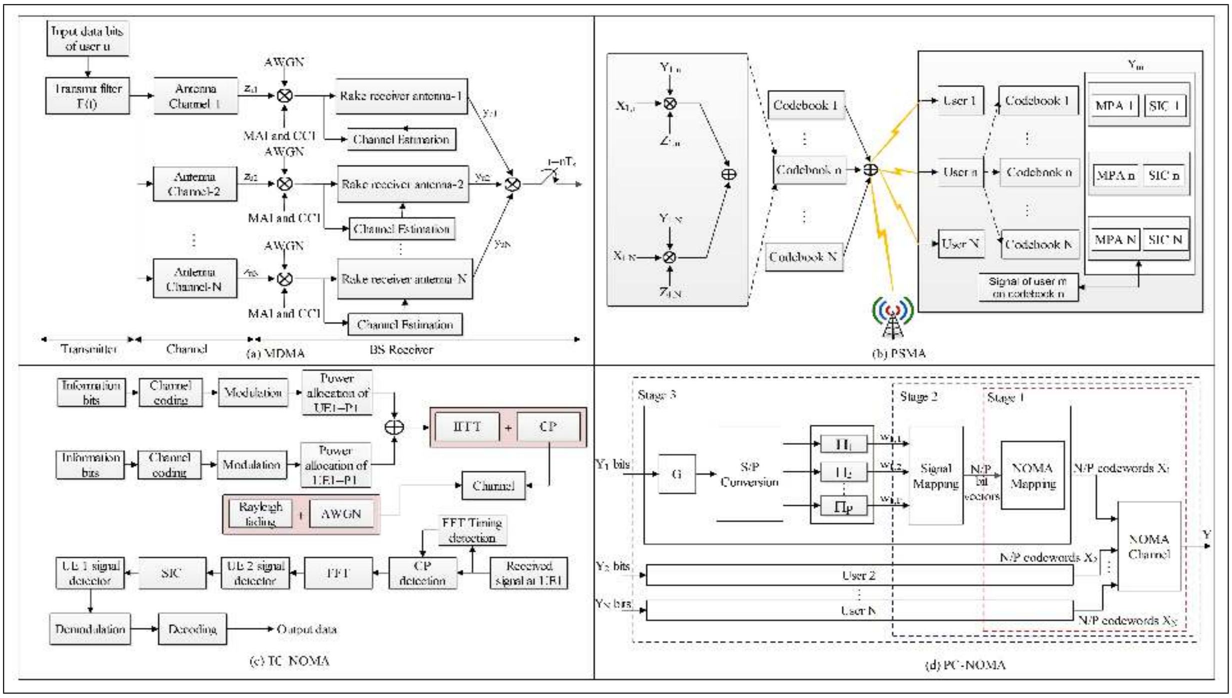
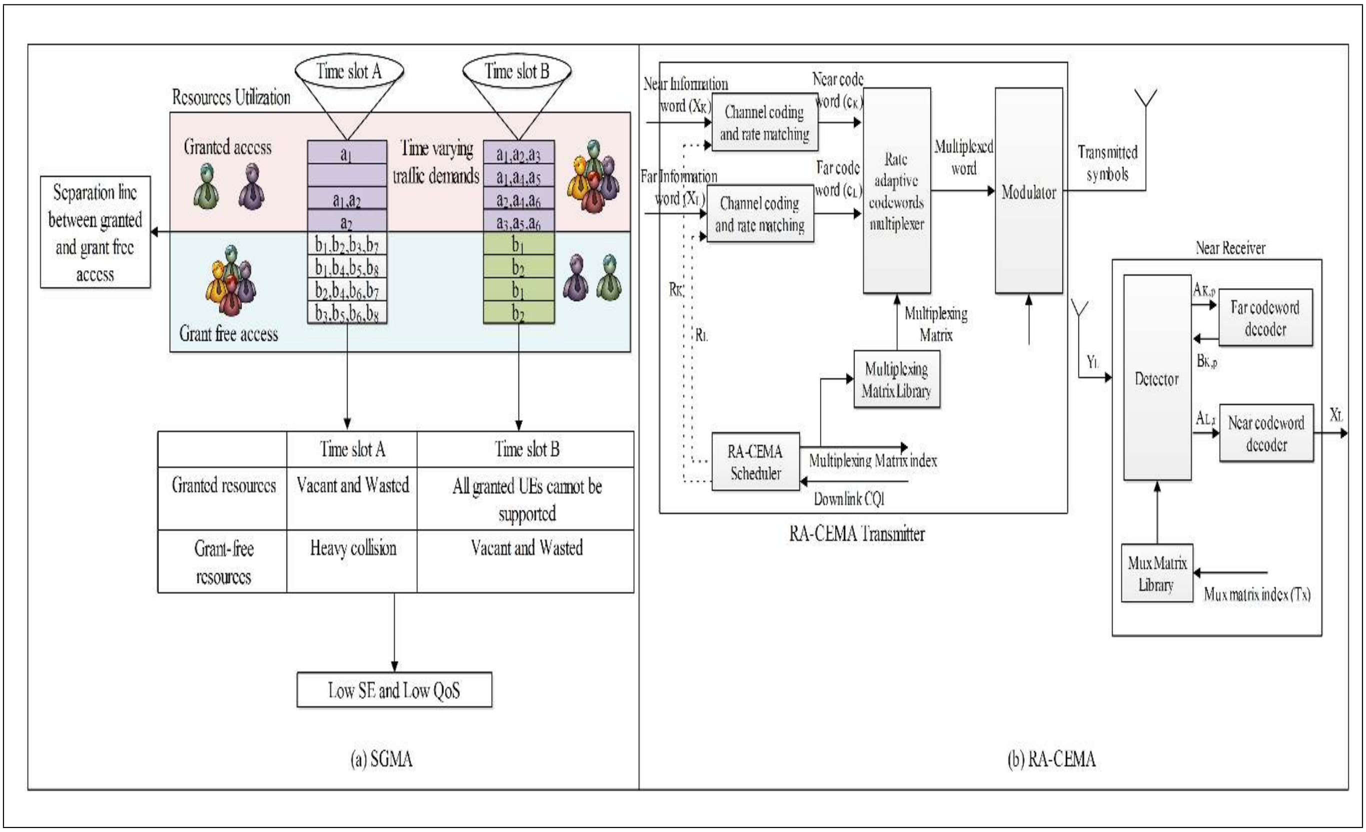


FIGURE 32: Block diagram of (a) MDMA (b) PSMA (c) TC-NOMA, and (d) PC-NOMA



	Time slot A	Time slot B
Granted resources	Vacant and Wasted	All granted UEs cannot be supported
Grant-free resources	Heavy collision	Vacant and Wasted

FIGURE 33: Block diagram of (a) SGMA, and (b) RA-CEMA

TABLE 13: Relative comparison between different CD-NOMA schemes

Type	**Acronym**	**Organizatio**	**Carrier type**	**Transmission Type**	**Receiver used**	**Technique used**	**Merits**	**Demerits**
Short spreading sequence	MUSA	ZTE	SC		MMSE-SIC	Short complex sequence	Block error rate (BLER) low, Large number of user access	High interference between users, Optimal spread symbols
	NOCA	Nokia	SC	Uplink	MMSE-SIC	Zadoff-Chu sequence	Reduce the PAPR	-
	NCMA	LGE	SC	Uplink	MUD+IC	Grassmannian line packing	Optimal non-orthogonal sequence	Transmitter overhead is high
	SSMA	Intel	SC	Uplink	MUD+IC ; MMSE-SIC	Orthogonal or quasi-orthogonal codes	Receiver complexity is low	Performance depends upon actual sequence length.
Long spreading sequence	GOCA	Mediatek	SC	Uplink	SIC	Group-based orthogonal/non-orthogonal sequences	Inter-group orthogonality	-
	WSMA	Ericsson	SC	Uplink/Downlink	MMSE-SIC	Welch bound coding	Receiver complexity is low	-
Coding	PDMA	CATT	MC	Uplink/Downlink	Belief Propagation (BP) [MPA-IC]	Irregular LDS	Provide Multidimensional diversity, Receiver complexity low, Irregular protection	Optimal pattern design
	SCMA	Huwaei	MC	Uplink/Downlink	MPA+IC	Multidimensional modulation	Signal space diversity gain	Optimal codebook design
	LDS-SVE	Fujistu	SC	Uplink/Downlink	MPA+IC	LDS and User signature vector extension (SVE)	Large diversity	Define LDS code and signature vector extension method
	LDS-CDMA	Fujistu	SC	Uplink/Downlink	MPA+IC	Sparese spreading CDMA	CSI independent	Redundant coding
	LDS-OFDM	Fujistu	MC	Uplink/Downlink	MPA+IC	Sparse spreading OFDM	CSI independent, provide wideband signals	Redundant coding
Lattice and Beam	LPMA		SC	Uplink/Downlink	SIC	Multilevel lattice code and multiplexing in power and code domain	User clustering independent	Specific channel coding
	BOMA		SC	Uplink/Downlink	SIC	Tiled building block	Receiver complexity low, easy structure	User pairing dependent
Interleaving	IGMA	Samsung	SC	Uplink/Downlink	MPA	Bit-level Interleaving(permutation matrix)	Low coding rate,Sparse grid Mapping	Transmitter overhead is high
	IDMA	Nokia	SC		Elementary signal estimator(ESE)+IC (IMD)	Bit-level Interleaving	Large diversity gain/ Low coding rate, Randomized the mutual interference	Interleaving design
	RDMA	Mediatek	SC	Uplink	SIC	Cyclic shift based time-frequency repetition	Easy implementation	-
	LCRS	Intel	SC	Uplink	ESE-PIC	Bit-level spreading	High code gain	Users' separation at receiver depends upon its structure
Scrambling	RSMA	Qualcomm	SC	Uplink	Matched filter + IC (MMSE-SIC; ESE-PIC)	Low cross-correlation Sequence scrambling	Fit for asynchronized scenario	Not suitable for SE, and requires synchronous multiplexing with OFDM
	LSSA	ETRI	SC	Uplink	MMSE-SIC	User-specific bit-level inter leaving/permutation pattern	Low rate FEC code or moderate one with repetition, Large number of signatures	-
Power domain	PD-NOMA	NTT Do-CoMo	SC	Uplink/Downlink	SIC	Signals separated through different power levels	High SE and low outage probability	Error propagation

used to provide the same codebook to multiple users. Fig. 32 (b) shows the usage of the same codebook by multiple users. In SCMA, the usage of the same codebook produces interference among each other. To overcome it, PSMA reused a codebook in the coverage area of each BS more than once, which enhanced the network SE. In this technique, at the receiver side, MPA based SIC detector is used to separate the signal of each user. The performances of PSMA were evaluated through the heterogeneous cellular network in terms of the system sum-rate and QoS of users by considering system-level and transmit power constraints, respectively. The numerical results show that the PSMA and SCMA, and PD-NOMA improved the SE up to 50%.

5) TC-NOMA

These codes are error-correcting and theoretically produced the results equivalent to Shannon's capacity theorem. This extraordinary performance is due to the use of two encoders, and an interleaver at the transmitter and two decoders and a de-interleaver at the receiver [366]. The block diagram of NOMA with turbo coding is shown in Fig. 32 (c). According to [367], performance results show that the NOMA with turbo codes outperformed NOMA without coding, and the BER is reduced at the receiver side.

6) PC-NOMA

It is based on channel polarization, where the combination of binary polar codes and signal modulation decomposed the original NOMA channel into multiple bit polarized channels by using a three-stage channel transform (user→ signal → bit) partitions [368]. The authors proposed two schemes. In the first scheme, channel transformation-sequential user partition (SUP) and the parallel user partition (PUP) are used. In the SUP-based PC-NOMA system, a worst-goes-first strategy was proposed to determine the user partition order, which improves the system performance by the enhanced polarization effect among the user synthesized channels. At the receiver side, a joint successive cancellation detection and decoding scheme was developed. It was analyzed through the channel polarization principle. On the other side, in the PUP-based PC-NOMA system, a parallel detection scheme was developed to reduce the processing latency. The numerical results show that the PC-NOMA scheme outperformed TC-NOMA in terms of block error ratio and throughput.

7) SGMA

This technique was proposed by [369] to ensure the QoS of users. The goal of the proposed scheme was to reduce the latency and signalling overhead, as shown in Fig. 33 (a). In this scheme, complete or part of the available resources can be shared by both the grant access and grant free access scheme [369]. Let X be the number of RBs/subcarriers of the wireless network, D^g and D^{gf} represents the demand set of grant access and grant free access, respectively, R^g and R^{gf} represents the available resources set for grant access and grant free access, respectively and M shows the mapping between the demand set and available resources, i.e., $D^g \xrightarrow{\text{M}} R^g$ and $D^{gf} \xrightarrow{\text{M}} R^{gf}$. Then, according to SGMA, $\forall R^g \neq \emptyset, R^{gf} \neq \emptyset \rightarrow R^g \cap R^{gf} \neq \emptyset$. SGMA decreases the BER and improves the throughput of the network as compared to SCMA, PDMA, MUSA, and IDMA.

8) BDM

Bit division multiplexing (BDM) is a physical layer sub-channel technique used to overcome the limitations of time-division multiplexing (TDM) [370]. This technique enhances the transmission efficiency of scalable video broadcasting. It can be easily applied to higher-order constellations because it provides flexibility in channel resource allocation using the conventional hierarchical modulation technique. BDM also assigns the fixed number of bits from the multiple symbols over the sub-channels by exploiting high-order modulation schemes' inherent characteristics, i.e., multiple unequal error protection. In contrast to TDM, BDM increases the transmission rate by decreasing the SINR across the multiple sub-channels.

9) GSOMA

It is an amalgamation of SOMA and conventional TDD [361], [371]. The authors observed in [361] that when in any group, only one user is left and no blanking was used, then GSOMA behaves like SOMA. In contrast, when only one group is left with the maximum number of users, GSOMA behaves like conventional TDD. Therefore, a properly designed GSOMA is required, which provides the advantages of both SOMA and conventional TDD. GSOMA enhances the aggregate rate concerning conventional TDD when more groups are to be scheduled. Similar to conventional TDD, in GSOMA, pilot sequences are also mutually orthogonal, allowing joint channel estimation without interference for all users in each group. The authors in [361] proposed a general framework of GSOMA and show that it works better than the TDD and conventional SOMA.

10) NORA

This random access scheme was proposed by [372] to reduce the large random access (RA) delay so that the performance between the UEs to carried out mMTC can be improved. The key idea behind this scheme was to overcome the congestion problem by using the SIC technique. First of all, it identifies the multiple UEs with an identical preamble by using the difference between their arrival time. Then, NORA enables power domain multiplexing to avoid the collision between the UEs and uses the SIC technique at the BS for preamble detection. Using NORA, multiple UEs simultaneously received the message by using limited PUSCH resources. In comparison to ORA, this scheme provides a 30% increase in throughput of the RA process and reduces the required preamble transmissions and access delay up to half when the total number of UEs is near the RA throughput.

FIGURE 34: Open issues and research challenges

V. OPEN ISSUES AND CHALLENGES

The use of NOMA variants for the 5G environment is still in its infancy. Several open issues and research challenges need to be addressed to realize its effect feel to the end-users. In December 2015, Huwaei proposed three variants of MA-NOMA, SOMA, and RA-CEMA. Most of the work has been done only in PD-NOMA and CD-NOMA. This section discusses the current and future communication challenges by using NOMA variants as shown in Fig. 34.

A. OPTIMAL WIRELESS POWER TRANSFER

This technique improves the lifespan of energy-constrained devices. Energy harvesting is based on the solar, wind, and thermoelectric effects, but these are not feasible as they rely on the location, environment and day time. To overcome it, harvesting from RF signals has been used so that the energy of the battery constrained devices can be improved. The implementation of NOMA with WPT for IoT application is an open issue which needs to be resolved to improve the network EE [373], [374], [375]. In spite of an improvement in EE, the management of co-channel interference along with energy harvesting is also an open issue.

B. IMPERFECT CSI

It has been observed that in NOMA, lots of work already been done by the researchers with perfect CSI for resource allocation and multi-user detection. However, perfect CSI is not possible due to feedback and channel estimation errors. It has been observed that when users' CSI is not known, then it results in interference. This happened because, with imperfect CSI, signals received from other user's signals cannot be removed completely. So, to handle the model with imperfect CSI, there is a need for perfect joint precoders to remove the interfering signals from the BS and a more advanced channels estimation algorithm to attain the more accurate channel information. Considering the aforementioned discussion, it is an open issue that needs to be resolved to reduce the effect of errors [376], [377].

C. SECURITY

In each generation of wireless communication system, security is an important issue that needs to be addressed. The signal broadcasted through a wireless channel requires significant attention as it is vulnerable to eavesdropping. The author in [378] proposed an appealing technique to improve the security of the wireless channel by using the cryptographic technique at the physical layer. In contrast, to [378], the authors in [379] proposed a solution to improve the secrecy of the network. Moreover, it improves the capacity of the channels concerning the eavesdropper's channel, but with a change in generation, new techniques are required to improve the physical layer security [380].

In NOMA, the security of the physical layer is not exploited to its full potential. In [381], the authors discussed the physical layer security issue by using stochastic geometry in a large-scale network employing a single antenna at NOMA users. In this technique, the BS communicates with the NOMA users, distributed randomly in a cell. To improve the security of the physical layer, a protected zone is used around the BS so that the intended users acquire more capacity in comparison to eavesdrop users. The authors in [382] implemented a multiple antenna-based NOMA and proposed a technique to improve the security of the physical layer. In this technique, the authors generated an artificial noise around the BS to decrease the capacity of the eavesdropper's channel. In [383], the authors explored the security issue in SISO-NOMA networks. However, still, security is an open issue for the NOMA technique, especially for the cases of MIMO and mMIMO [384].

D. IMPROVEMENT IN PHYSICAL LAYER TECHNOLOGIES

The pre-existing NOMA schemes worked either on bit-level or symbol-level operations; thus, they did not provide a globally optimal design. To overcome this issue, a joint technique consisting of both bit and symbol level needs to be designed. Still, it is sensitive towards certain channel conditions and needs further attention to cope with the practical scenarios. Despite the design at the transmitter side, the detection of signals at the receiver side is another physical layer technology that needs improvement. The traditional technique requires many iterations to detect the symbol and encode the channel, which increases latency. Hence, the reduction in latency and complexity is an open issue that needs to be addressed to improve system reliability.

E. CR INSPIRED NOMA

NOMA is suitable for 5G applications that improve the SE. When NOMA is integrated with CR, it guaranteed the QoS for the poor channel condition users as it treats those users as a PU. Still, the performance of the SU can be degraded as they get services only after the weak channel condition user's QoS is met. This is the reason why CR-NOMA cannot fulfill the QoS requirements of all users, which needs to be addressed [385], [386].

F. HARDWARE COMPLEXITY

In NOMA, the presence of a SIC detector increases the hardware complexity, which first separates the high power level signals as compared to the lower power level to obtain users' data. It has been observed that when several users or a fast signalling transmission is required, the detection delay increases, which can affect the battery of the UEs. Hence, to implement the NOMA in ultra-dense networks, UEs must be equipped with sufficient battery, which is practically impossible. To resolve it, fair power allocation and effective user clustering techniques are required.

G. ERROR PROPAGATION IN SIC IMPLEMENTATION

When SIC is carried out at the receiver side, then the users with better channel conditions subtract the signals of weak channel condition users' to estimate their data rate. But, in practical situations, the SIC detection affects the receiver because it is not possible for the NOMA system to estimate the channel ideally. This happened due to hardware complexity, timing offset (TO), carrier frequency offset (CFO) type-related impairments. So, error propagation and erroneous detection usually occur in the SIC process. To resolve the aforementioned issue and enhance the QoS, an improvement in the estimation quality of mentioned hardware impairments is needed.

H. GRANT FREE NOMA

In OMA, the access grant-based transmission in an uplink scheduling and downlink resource allocation results into high transmission latency and signalling overhead. However, an MA technique requires an MA technique that overcomes the grant-free transmission and provides low transmission latency and low signalling overhead. The aforementioned issues are resolved with the usage of NOMA to ensure massive connectivity for the case where short packets are to be transmitted. Therefore, a contention-based NOMA is a promising solution for the scenarios where one or more pre-configured resources are allocated to contending users. It was also found that integrated protocols such as random back-off techniques suitably eliminate the non-orthogonal collisions, which become helpful in a rate reduction of dropping packets. Moreover, NOMA removes the dependency to access the grant procedure, due to which BS cannot obtain any information related to the users. Hence, to overcome this issue, compressed sensing (CS) based algorithms need to be overcome due to the sparsity of user activity.

I. RECEIVER DESIGN

The SIC employed receiver, the complexity, and error propagation degrade the performance of the users. Therefore, to overcome this issue, a more accurate non-linear detection algorithm with high performance is required, reducing the influence of the error propagation. However, the MPA-based receiver has high complexity, but it efficiently removes the error propagation issue using the Gaussian distribution approximation technique. It provides more accurate and better results when the number of connections increases. Moreover, it was also found that MPA simultaneously decodes and detects the data symbols, especially for the graphs having variable and observation nodes. These receivers also decode, demodulate, and exchange the data symbols more efficiently to improve signal detection performance. But, the issues such as efficient receiver design, error propagation, and signal detection accuracy need to be exploited to strengthen the performance at the receiver side [387], [388], [389].

J. RESOURCE ALLOCATION

It is used to assign the radio resources to users, which improves their throughput, data rate, EE, and user fairness. When the number of users becomes large in a multi-cell scenario, then the resource allocation to users becomes difficult as the spectrum has limited radio resources. NOMA has efficiently utilized the resources due to its ability to serve multiple users simultaneously using different power levels. However, assigning resources to users using the NOMA technique is quite complex due to the presence of co-channel and cross-channel interference [390]. A proper resource allocation scheme is required to mitigate these interferences, which reduces the impact of error propagation.

K. PILOT ALLOCATION

The transmission of multiple signals is carried out in an overlapped fashion, due to which the problem of intra-user interference and error propagation becomes severe. It results in a degradation in the performance of NOMA as compared to OMA systems. To implement error and interference-free NOMA, the positions of the pilot and its allocation is an important issue that needs to be reinvestigated. It also reduces the error and enhances the performance of the NOMA-based system.

L. OTHER ISSUES

It has been observed that NOMA enhances the SE and EE of the network when these are used in HetNets, UAVs, V2X, and WSNs [391], [392], [393]. However, NOMA improved the system efficiency of these applications. However, various open issues still need to be addressed, such as in V2X and UAVs, mobility of the vehicles, and co-channel interference. In HetNets, co-channel, cross channel, and NOMA interference is severe. All these issues need to be addressed to improve the data rate, SE, EE, reliability, throughput, and OP system.

VI. CONCLUSION

In this paper, different NOMA variants for the 5G environment are explored. The survey is divided into four parts. The first part of the survey discussed the background and standards of NOMA in detail. NOMA history is analyzed based on year-wise improvements in traditional techniques. Then, the capacity comparison of OMA and NOMA and advantages of NOMA over OMA are analyzed. The second part of the paper discussed the NOMA variants in the power domain. Then, NOMA in D2D communication, cooperative communication, cognitive-communication, M2M communication, SWIPT, MIMO, mMIMO, SDN, MEC, UAVs, VLC, mmWave, Het Nets, and V2X are discussed. The comparative analysis of the existing variants of NOMA is performed based on transmission scenario, techniques used, throughput, sum-rate, EE, latency, capacity, and random access probability. The third part of the survey discussed the code domain NOMA variants. Finally, the open issues and challenges of code and power domain variants of NOMA are discussed.

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