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A Thorough Review of Prospective Technologies for 5G/Beyond 5G Wireless Networks

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Abstract

Recently, wireless communication systems have relied on the orthogonal multiple access (OMA) principle to distribute radio resources to users through orthogonal access. However, as the number of users increases, OMA techniques may struggle to meet the demanding requirements of 5G and beyond 5G (B5G) networks, particularly in terms of high spectral efficiency (SE) and user capacity. This survey thoroughly explores the key goals and needs of 5G networks, such as ultra-high data rates, ultra-low latency, massive device connectivity, and energy efficiency. By providing a detailed analysis, the survey outlines the fundamental technologies that enable 5G/B5G networks. Non-orthogonal multiple access (NOMA) is identified as a promising method to improve SE and support large-scale connectivity without sacrificing system performance. NOMA is also seen as an emerging technology that can enhance system throughput, data rates, and latency in future 5G/B5G networks. Integrating NOMA into cognitive radio networks (CRNs) and multiple input multiple output (MIMO) systems, showing that MIMO techniques can greatly improve CRN based NOMA systems. The study also looks at various research challenges related to NOMA, including space division multiple access, rate splitting multiple access, simultaneous wireless information and power transfer, physical layer security, unmanned aerial vehicles, and vehicle-to-everything networks, and proposes possible future research directions. Furthermore, applications of artificial intelligence and machine learning for 5G and B5G are also the scope of this survey. In conclusion, this survey provides a foundation for advancing 5G/B5G wireless networks through current technological developments.

Keywords: Orthogonal multiple access; Non-orthogonal multiple access; Cooperative non-orthogonal multiple access; Cognitive radio-nonorthogonal multiple access; Multiple input multiple output-non-orthogonal multiple access; Cognitive radio-multiple input multiple output-nonorthogonal multiple access; Space division multiple access; Rate splitting multiple access.
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1. Introduction

Non-orthogonal multiple access (NOMA) has been consistently identified as an effective multiple access (MA) technique for increasing cellular wireless network capacity.[1,2] Multiuser superposition transmission (MUST) in the third generation partnership project (3GPP)- long term evolution (LTE) and layered-division multiplexing (LDM) in the ATSC 3.0 digital TV standard have both used NOMA.[3] The advanced television systems committee (ATSC) digital TV transmission system is also built on the NOMA principle, which permits many streams of data to be superimposed on the same channel. As a result, the spectral efficiency of the TV broadcasting systems may be enhanced.[4] Furthermore, the deployment of NOMA is regarded as a significant aspect in fifth generation (5G) and beyond 5G (B5G) mobile systems.[5-13] For the future 5G wireless cellular networks, we investigate the principle of NOMA. OMA approaches are used in existing fourth generation (4G) wireless systems such as LTE and WiMAX. Multiple access techniques (MAT): There are two aspects to the MAT. The very first component is known as orthogonal, while the second is known as non-orthogonal.[14] Different accessing techniques were employed under both orthogonal and nonorthogonal schemes. Frequency division multiple access (FDMA), time division multiple access

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(TDMA), and orthogonal frequency division multiple access (OFDMA) techniques are used in the orthogonal section, while power domain and code domain multiplexing techniques are used in the non-orthogonal section. NOMA and OFDMA both are MATs. NOMA utilises power domain or code domain multiplexing to serve multiple users (*i.e.*, UEs) in a cell, however OFDMA uses frequency/time resources to service multiple users (*i.e.*, UEs) in a cell. The orthogonal multiple access techniques are superior for the packet domain,[15,16] since it has a channel-aware time and frequency plan. One of the disadvantages of NOMA, is that it requires more power from a remote user from the base station (BS) and has a larger interference ratio due to larger connectivity, which increases to receiver's complexity.[17] Table 1 detail the comparative performances of NOMA and OMA techniques. The basic mechanism of NOMA is to serve multiple users at the same time/frequency by allocating distinct power levels; for example, users who are far away from the BS require more power to decode information while maintaining connectivity than users who are close to the BS and have reliable communication. As a result, the receiver becomes more sophisticated, and more power is needed.

Table 1: The capacity comparison of OMA and NOMA.

Specifications	OMA	NOMA
Spectral efficiency	Lower	Higher
User capacity	Less	More
Number of clusters	More	Less
Energy consumption	Less	More
Number of pairs	Large	Lower
System throughput	Smaller	Larger
Receiver complexity	Low	High

In OMA, on the other hand, each user can employ orthogonal resources within such a defined time slot, frequency range, or code to minimize MA interference, resulting in lower power usage and receiver complexity. Due to providing connectivity to a limited user and allocating resources for a set duration, OMA's throughput is lower. As a result, multiple users must wait for the first user to be served, but NOMA serves several users simultaneously by allocating various power levels to individuals. Table 1 provides the capacity comparison between OMA and NOMA in terms of its specifications such as spectral efficiency, latency, user capacity, energy consumption, receiver complexity, user pairs, cluster size, and system throughput.[18] However, TDMA, FDMA, and code division multiple access (CDMA) is all used in OMA systems. None of these methods, however, can match the high requirements of upcoming radio access systems. The following are some of the properties of OMA systems. Because TDMA transmits messages to each user in non-overlapping time frames,[19] TDMA-based networks need precise timing synchronization, which could be difficult, especially in the uplink. Data for each user is allocated to a portion of subcarriers in FDMA systems, such as OFDMA. In order to segregate users on the same channel, CDMA use codes.[20] Future 5G wireless systems and beyond will encounter additional difficulties as growth of wireless traffic at an exponential rate, driving significantly improved spectral efficiency, increased user capacity, and reduced latency.[21,22]

Although academics and industries are suggested numerous 5G multiple access schemes, such as power-domain NOMA,[23] SCMA,[24,25] PDMA,[26,27] LDS,[28] LPMA.[29] These techniques are through on the same key aspect, where numerous users are served in each orthogonal resource block, for example, a time slot, a frequency band, a spreading code, or an orthogonal spatial degree of freedom. However, in traditional OMA techniques, cell phones exchange resources in an orthogonal fashion, and because of the restricted transmission bandwidth, these OMA methods would abide from substantial obstruction difficulties when there is a huge demand for users. As a result, upcoming wireless systems involve substantially better spectrally efficient access network devices. The purpose of this literature review is to offer a complete description of most recent NOMA-based networks framework and its advancements. In addition, cluster-based NOMA is introduced in the recommended system for lowering complexity. Due to the huge demand in users, various studies have addressed for both user 1 and user 2. The successive interference cancellation (SIC) is used to decode each user's signals, which adds to the computational requirements. As a result, clustering is proposed to assist reduce the increased complexity.[30,31] Then, using SIC, one could prevent interference while achieving a lower complexity goal. Thereafter, channel state information (CSI) serves as a framework for SIC, detecting weak and strong users' signals and allocating power correspondingly. SIC decoding cannot be decided immediately by the BS with imperfect CSI. As a result, the first step is to obtain a specific SIC decoding priority. Our major contributions are mentioned below:

- A complete survey is provided for cellular networks, device-to-device transmissions, and wireless sensor networks on the application of NOMA signaling.
- The imperfectness in the SIC receiver is addressed, as well as their effect on the NOMA system is also studied.
- This review covers a comprehensive overview of the incorporation of cooperative PD-NOMA into CRNs, as well as the latest multi-antenna systems (such as CR-NOMA, and CR-MIMO-NOMA, among others).
- Provides a detailed framework for downlink mm-Wave multiple user MIMO-NOMA networks featuring limited feedback.
- Provides a detailed framework for space division multiple access (SDMA), rate splitting multiple access (RSMA), simultaneous wireless information and power transfer (SWIPT), physical layer security (PLS), unmanned aerial vehicle (UAV), and vehicle-to-everything (V2X) networks have been explained with future research directions and their potential applications.

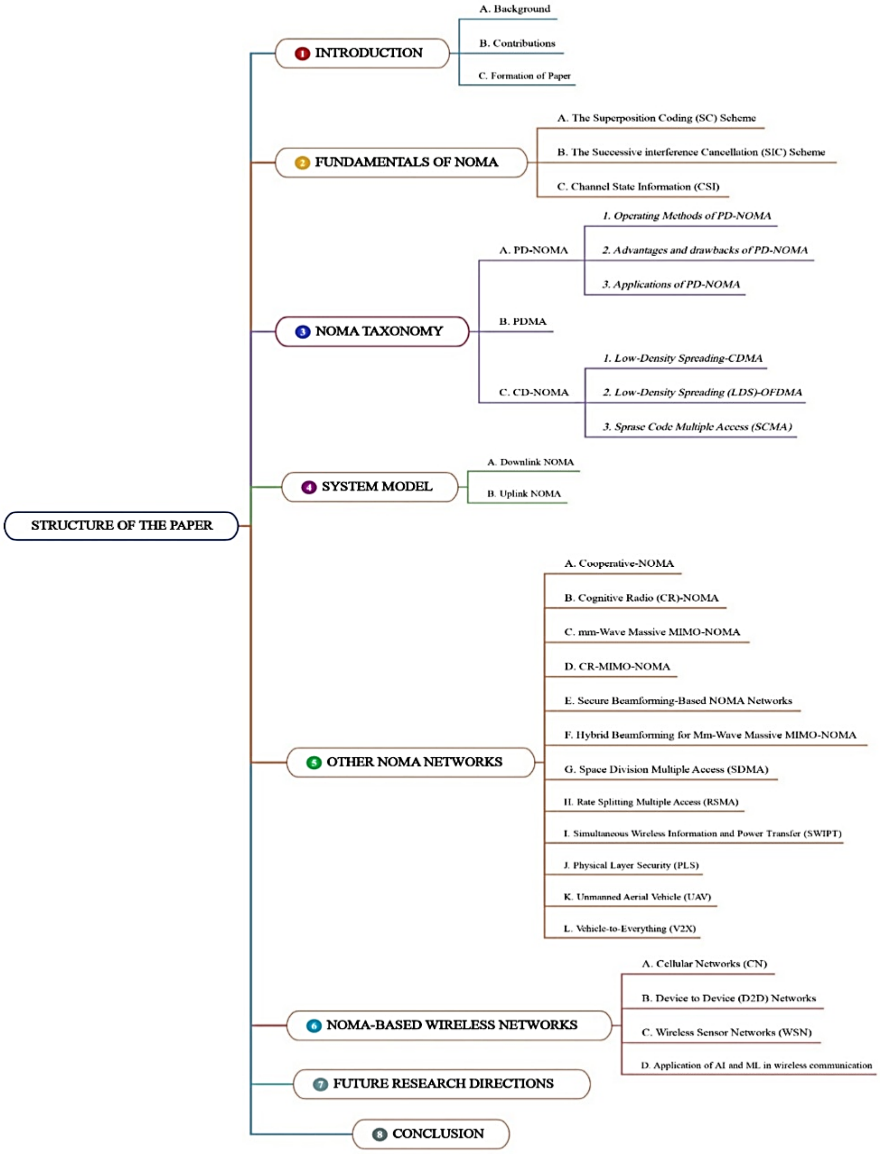

Fig. 1: Structure of the paper.

The remainder of this paper is arranged in the following manner. The basic concepts of NOMA and its major categories and its system model are presented in sections 2, 3, and 4, respectively. In section 5, other NOMA based networks like cooperative NOMA, CR-NOMA, MIMO-NOMA, CR-MIMO-NOMA, mm-Wave massive MIMO-NOMA, beamforming-based MIMO-NOMA networks, SDMA, RSMA, SWIPT, PLS, UAV, and V2X networks are proposed, and their working principles are demonstrated in detail. In section 6, we will look at how NOMA is used in cellular networks (CN), device-to-device (D2D) communications, WSN and the applications of artificial intelligence and machine learning for 5G and B5G systems are also highlighted. Further, we also discuss major research challenges via future research directions in section 7. Finally, section 8 draws the conclusion of this survey article. Fig. 1 illustrates the organizational structure of this paper, while Table 2 provides a comprehensive list of acronyms used throughout the manuscript.

2. Fundamentals of NOMA

The study investigates the temperature impact on the biological tissue of human skin subjected to heat from a moving laser. The mathematical model used in the study comprises multiple layers of biological tissue. It considers variations in the speed and radius of the laser to assess the maximum temperature reached after tissue welding. In 5G wireless networks, the NOMA approach is typically known for optimal spectrum usage. NOMA operates in the power domain and is based on OFDM. In OFDM, each user could use all available subcarriers, however in NOMA, several users can share the same subcarrier, increasing spectrum efficiency.[32] NOMA is clearly distinguishable from other multiple access methods that give users with orthogonal access in time, frequency, code, or space.[33,34] presented NOMA as a possible radio access method for 5G cellular infrastructure. Each user

Table 2: List of abbreviations.

Acronym	Acronym Description
MAT	Multiple Access Techniques
OMA	Orthogonal Multiple Access
NOMA	Non-orthogonal Multiple Access
MUST	Multi-User Superposition Transmission
MUD	Multi-User Detection
3GPP-LTE	3rd Generation Partnership Project Long Term Evolution
SC	Superposition Coding
SIC	Successive Interference Cancellation
FDMA	Frequency Division Multiple Access
TDMA	Time Division Multiple Access
CDMA	Code Division Multiple Access
OFDMA	Orthogonal Frequency Division Multiple
OFDM	Orthogonal Frequency Division Multiplexing
LDM	Layered Division Multiplexing
PD-NOMA	Power Domain Non-orthogonal Multiple Access
SC-NOMA	Single Carrier Non-Orthogonal Multiple Access
MC-NOMA	Multi-Carrier Non-orthogonal Multiple Access
CD-NOMA	Code Domain Non-Orthogonal Multiple Access
LDS-CDMA	Low Density Spreading Code Division Multiple Access
LDS-OFDMA	Low Density Spreading Orthogonal Frequency Division Multiple Access
SCMA	Sparse Code Multiple Access
PDMA	Pattern Division Multiple Access
LPMA	Lattice Partition Multiple Access
FCC	Federal Communications Commission
SE	Spectral Efficiency
EE	Energy Efficiency
RF	Radio Frequency
AF	Amplify and forward
CN	Cellular Networks
D2D	Device-To-Device
WSN	Wireless Sensor Networks
SNR	Signal to Noise Power Ratio
MRC	Maximal Ratio Combining
AWGN	Additive White Gaussian Noise
BER	Bit Error Rare
CSI	Channel State Information
CSIT	Channel State Information Transmitter
CSIR	Channel State Information Receiver
CQI	Channel Quality Information
C-NOMA	Cooperative Non-orthogonal Multiple
NR	New Radio
CR	Cognitive Radio
SU	Secondary User
PU	Primary User
LU	Licensed User
CRN	Cognitive Radio Network
SS	Spectrum Sensing
ED	Energy Detector
CR-NOMA	Cognitive Radio Non-Orthogonal Multiple Access

Acronym	Acronym Description
mm-Wave	Millimeter-Wave
mMIMO	Massive Multiple Input Multiple Output
MU-MIMO	Multi-User Multiple Input Multiple Output
CR-MIMO-NOMA	Cognitive Radio Multiple Input Multiple Output NOMA
SDMA	Space Division Multiple Access
RSMA	Rate Splitting Multiple Access
SWIPT	Simultaneous Wireless Information and Power Transfer
IoT	Internet of Things
PLS	Physical Layer Security
UAV	Unmanned Aerial Vehicle
V2X	Vehicle-to-Everything
V2V	Vehicle-to-Vehicle
V2I	Vehicle-to-Infrastructure
V2P	Vehicle-to-Pedestrian
V2C	Vehicle-to–Cloud
SISO	Single Input Single Output
AN	Artificial Noise
IUI	Inter-User Interference
BF	Beamforming
ZF-BF	Zero Forcing Beamforming
BS	Base Station
UE	User Equipment
BC	Broadcast Channels
SCST	Single Cell Single-Tier
SCMT	Single Cell Multi-Tier
MCST	Multi Cell Single-Tier
MCMT	Multi Cell Multi-Tier
QoS	Quality of Service
DoS	Denial of Service
CT	Cross Technology
ST	Secondary Transmitter
SR	Secondary Receiver
SN	Sensor Node
SIN	Sink Node
AI	Artificial Intelligence
ML	Machine Learning
DL	Deep Learning
SGF	Semi-Grant-Free

in NOMA can participate in the same spectrum and at the same time, with different individual power requirements separating them. At the transmitter side, NOMA employs the SC approach and the SIC approach at the receiver side to distinguish between users in both the uplink and downlink channels. For successfully implementing real-time power allocation and SIC algorithms in cellular networks, substantial processing power is required. A description of the operating mechanism of SC and SIC is presented in the next sub-section.

2.1 The superposition coding scheme

NOMA superimposes different users in a single resource (frequency/time/code) by allocating different power levels to them. As a result, using the view of superposition coding, multiple users can access the same channel in a non-orthogonal fashion. In many wireless networks, namely BS is collaborating with many cellular users, Wi-Fi access points distributing data among numerous users, hotspots located at airports/shopping malls, military superior sending detailed guidelines to several parts, and so on. There seems to be a transmission scenario where a particular source must interact with a large number of receivers. In these cases, the usual method of achieving communication is to employ standard OMA techniques, in which frequency/time/code domain is

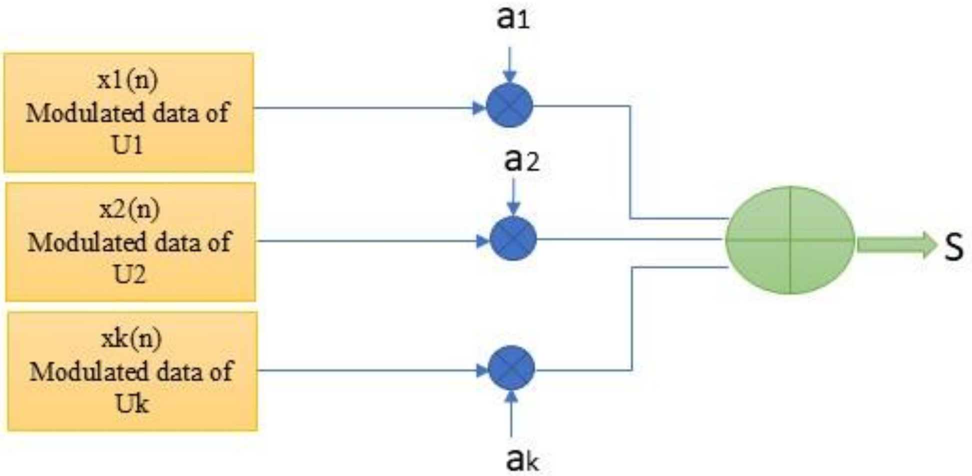

Fig. 2: Illustration of superposition coding scheme.

used to assign orthogonal channels to all the individual users. From an information-theoretical aspect, this strategy is often not ideal in obtaining the capacity and sum-rate of the Gaussian broadcast channels (BC). As a result, the non-orthogonal approach, also referred as SC, is seen as a prominent scheme for obtaining the Gaussian BC's capacity.

Furthermore, superposition coding (SC) has the capability to increase spectral efficiency of the system.[35-38] SC was initially proposed and researched in Ref. [39] pioneering work, where it was offered as a way of concurrently conveying messages between a source and several receivers. In Ref. [40], the authors offered and explored various techniques for applying SC. In addition, the authors provide a set of rate pairs that are able to obtain greater spectral efficiency than conventional OMA systems, based on experimental data. TV Broadcasting, a teacher/speaker delivering a speech to persons of various abilities, and radio broadcast are all instances of SC. The SC is defined as a physical layer approach for transmitting several user's separate messages at the same time. From an operational and technological aspect, the SC technique may be thought of as a multi-layer modulation system, with each layer representing a separate user's modulated and coded message. Prior sending message to the channel,[41] the transmitter superimposes individual user message signals by combining all together to form a composite signal. Fig. 2 shows the basic transmitter that implements SC as well as the concept of a SC-based transmission system. More rigorous action is necessary in order to get deep insights into the principle of SC. Assume a multiple users transmission system that includes a source and U number of users. Consider that the source's total transmission power is limited to P watts, and that the user's baseband signal is u, $u = 1, 2, \ldots U$ which is represented by S_u, where S_u is a baseband/modulating signal or the result of utilizing a certain modulation and coding method, based on the kind of communication network. The study above, therefore, treats S_u as a modulating signal independent of its fundamental construction mechanism for numeric and expositional reasons. A source creates a superimposed composite signal, indicated as S, using the SC principle, which is then concurrently sent to all U consumers. At the source, the superimposed signal S is given in Eq. (1) expressed as:[35-38]

$$S = \sum_{u=1}^{K} \sqrt{a_u P S_u} \tag{1}$$

where a_u be the power allocation parameters of u users and $\sum_{u=1}^{K} a_u \leq 1$. Eq. (1) tells that, SC generates intra-user interference, that must be eliminated by each user u prior detecting their own code. As a result, in order to fully experience the benefits of SC, to decrease intra-user interference an efficient multiuser detection (MUD) approach is required. As a result, the next part covers the operating idea of SIC, which is a promising and reasonably simple MUD system to be employed at the user's receiver side.[42]

2.2 The successive interference cancellation scheme

Cover *et al*.[39] was the first to suggest the SIC technique. The SIC approach takes use of the differences in signal intensity among many of the signals of interest. The signals of users are decoded in predefined order according to the SIC principle. It indicates that after decoding one user's signal, a subtraction between such a signal and the composite signal is performed earlier detecting the next user message. As a consequence, signals of other users are seen as interference by the SIC user, while the latter is decoded with the advantage of the former's signal being eliminated. Before implementing SIC, it should be remembered that the user order must be arranged with the matching signal intensities. As a result, at the receiver, the stronger signal is first decoded, then subtracted from the combined signal, and the weaker signal is extracted from the residual. Each user hears the other interfering users as noise while the incoming signal is processed in SIC. In general, the mathematically stated process of superposed messages may be written as in Ref. [40]. The message $x_1(n)$ is decoded by a single user decoder at close range, whereas the message $x_2(n)$ is ignored. A distant user recovers its information in stages by using the received signal $y_2(n)$ and following the steps below. First, it uses a single decoder to decode the message of a nearby user $x_1(n)$. After this step, it subtracts $\sqrt{P_1} h_2 x_1(n)$ from the $y_2(n)$ to obtain $y_2'(n) = y_2(n) - \sqrt{P_1} h_2 x_1(n)$, where h_2 is the complex channel gain of a strong user. Finally, the message $x_2(n)$ of the strong user is decoded by employing another single user decoder on $y_2'(n)$.

2.3 Imperfect SIC

Signals for all users are superposed before transmission in NOMA, and then decoded at each SIC user. SIC works by sequentially decoding and removing signals until it gets the target signal. The decoding order at each user, on the other hand, must match the cancellation sequence's user index. If there is a mismatch, users will not get their signals and will have to request their messages from the BS, adding to the already lengthy processing time for a standard SIC receiver. We also study how well the SIC receiver works in the cancellation sequence when the decoding order changes from the user's list. The cancellation must be iterated by SIC until it discovers its own signal. If these two are out of sync, the recipient will get an incorrect message. Because decoding time is proportional to the number of iterations, the discrepancy would influence SIC computation time. For few users, an unusually long decoding times are recorded in a practical NOMA, and they are assumed that the cause may be any a malicious attack or deliberate fraud. Some works have been addressed in the literature that extended processing times be a sign of security concerns.[43-47] When the receiver's decoding order does not match with the desired signal, the effectiveness of a SIC receiver is examined in this study. The application of NOMA solutions is subsequently developed in small-cell network systems, users are able to share the channel in non-orthogonally manner via power-domain[48] or code-domain multiplexing,[49] to meet these demands for massive connectivity and broadband services. NOMA's improved spectral efficiency is due to the fact that it takes use of smart network resource reuse by multiplexing many users in the same frequency band and creating excellent signal perception procedures. In uplink networks, the authors explored few methods to achieve better user fairness in Ref. [48]. In Ref. [49], tree exploration algorithm and a SIC scheme is described with a low-complexity power regulation. In fact, resource management in NOMA systems may finds a lot of experimental research investigations.[48,49] The authors are concentrated mainly on resource management is based on different power levels in case of PD-NOMA, whereas the resources allocated in the frequency and code dimensions might be further researched in other NOMA networks to enhance system capacity.

2.4 Channel state information

In the wireless transmission, CSI offers an effective connection that is utilized to convey information from source to destination and represents the joint impact of power decrease over distance, scattering, and fading. The channel estimate is the name given to this entire procedure.[17] In multi-antenna systems, assisting CSI in optimizing the transmissions to better channel circumstances can result in high data rates and secure communications. The channel state information receiver (CSIR) and channel state information transmitter (CSIT) are the terms used to describe CSI at the receiver and transmitter, accordingly. CSI estimate is required, and it frequently quantifies and feeds back to the transmitter.

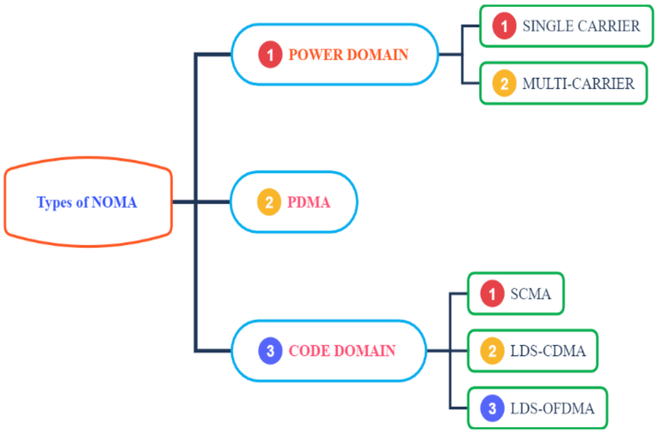

Fig. 3: The major categories of NOMA.

3. NOMA taxonomy

This section provides a detailed overview of NOMA subcategories, as illustrated in Fig. 3 and its integration with other wireless networks. The power-domain and code-domain multiplexing are the two basic types of NOMA:

- PD-NOMA: At the transmitter, it multiplexes multiple users on the same subcarrier at distinct power requirements, and at the receiver, SIC scheme is used to interpret the incoming signals.[34]
- CD-NOMA: To achieve overflow,[37,38] it employs sparse spreading sequences to distribute the signal of each user over various subcarriers. It might be converted to codebook-based methods, wherein the codewords are created by distributing codes which recognized by the respective the transceiver.

The presence of numerous mobile devices in a massively linked network encourages NOMA needs. Multiple accesses in the NOMA network serve to enhance spectral efficiency and low latency, which is significantly beyond the notion in the OMA network.[50] Spectral efficiency, throughput, user fairness, low latency, vast connection, computability, and other factors distinguish NOMA from OMA. Hardware complexity, error propagation in SIC implementation, optimal pilot allocation, and the demand for instantaneous CSI are among the many advantages of NOMA, as well as some problems in terms of NOMA implementation.[50] NOMA research in the future will encompass several approaches for employing NOMA in various applications of next-generation communication systems. CR, MIMO, and new radio (NR) are examples of such systems.

3.1 Power domain-NOMA

In most cases, power domain-NOMA is described as a single carrier (SC) NOMA method, wherein the users are allocated through unrelated resource blocks. Recent works, however, have attempted to adapt PD-NOMA to multi-carrier (MC) OFDMA systems.[51-54] OFDMA amalgamated with PD-NOMA is an exceptional event of MC-NOMA (which comprises SCMA and PDMA), these two techniques are presented earlier in the 5G investigation to implement the development of OFDMA based NOMA networks.[4] Unlike SC-NOMA, MC-NOMA in Refs. [55,56] uses various codes and patterns under SCMA/PDMA techniques to identify the users. The advantages, drawbacks, and industrial applications of PD-NOMA are highlighted in the next sub-section, which is followed by an explanation of the operating concept of PD-NOMA.

- **Operating Methods of PD-NOMA:** Fundamental concepts of NOMA are namely SC and SIC, these are essential to understand the principle of PD-NOMA. The SC approaches permit a single source to analyse information from several users simultaneously. In order to execute SC, every user gets a power allocation parameter to fulfil the requirements of the system. SC is accomplished at the BS in the downlink situation by signal components are directly adding from various users. For instance, the BS communicates a superposed signal from various users by setting various power allocation coefficients for each user whereas maintaining total transmitted power management. Power allocation in NOMA is done by taking into account two system preferences: user fairness and user QoS needs. To guarantee that each user is treated equally, users are ranked according to their channel conditions, with users with poor channel gains receiving highest power levels and those with strong channel gains receiving lowest power levels. A CR-NOMA technique is employed to certify that the QoS needs of all users are met. All the users are sorted as per QoS needs in this case, and the power distribution strategy is intended to fulfil the QoS needs of each user. SIC realises MUD at the receiver side during reception. Due to the near far problem, there may be significant changes in the channel conditions of various users. The key notion underlying SIC is that each user's communication is decoded one by one. When one signal is decoded, it is deducted from the combined message before the following user's signal is decoded. According to the SIC, when one user's signal is decoded, other user's messages are classified as interference, therefore the message of the remaining users may be detected by the benefit of without causing interference from the previous because it has previously been eliminated. To execute SIC, each user is initially arranged rendering to the strength of the received signals, by the strongest user's data being decoded first and then subtracted from the combined signal, and weaker users being separated from the residue. It's worth noting that in signal reception, other user's signals are classified as interference.
- **Advantages and drawbacks of PD-NOMA:** Because PD-NOMA has so many appealing qualities, it is quickly emerging as a key enabling technology for future wireless networks. Enhanced data rate, huge connection, and dependable and reduced latency communications are all major criteria of 5G wireless networks, which may be seen at the cost of complexity of PD-NOMA network. The benefits and drawbacks are mentioned below in detail.
- **Improved capacity and spectral efficiency:** In OMA scheme, each user is assigned a particular orthogonal subcarrier. PD-NOMA makes effective use of spectrum by multiplexing in the power domain, allowing numerous users to use a single subcarrier. Another significant advantage of NOMA system is their increased capacity. It has been analytically demonstrated that when optimal resource allocation is used in both systems, NOMA capacity performance always outperforms any OMA system.[57]
- **User fairness:** The fairness-based PD-working NOMA's premise indicates that the system's weak users are given more authority. This ensures that PD-NOMA can achieve throughput fairness for all users. User fairness is ensured by allocating an optimum power allocation algorithm.[58]
- **Massive connectivity:** The utilization of non-orthogonal resources in power domain NOMA proves that the existing quantity of resources does not strictly limit the users count who may be maintained. That means NOMA has the potential to significantly increase the number of users simultaneously, particularly in instances when rank is lacking. This tests its capacity to support a large number of connections.
- **Low transmission latency and signaling cost:** The user's obligation is to begin a ordering appeal to the BS for traditional OMA that relies on access grant requirements. When BS gets a request from a user, in uplink transmission its setups the user's ordering and replies by sending a clear-to-send message on the downlink network. Due to this, there will be a excessive transmission delay and signaling complexity, and the key requirement of 5G networks to achieve a user latency of less than 1ms would not be met. NOMA methods, do not require any pre-ordering, resulting in reduced transmission delay.
- **Drawbacks of PD-NOMA:** In spite of all of its effectiveness and benefits, the PD-NOMA system has several practical implementation challenges. Hardware complexity, computational issues, and inter-cell interference are among the flaws. Because PD-NOMA systems require SIC implementation, the SIC method introduces additional complexity, that might be difficult for employing large number of users in future wireless networks. Advanced MIMO techniques are necessary to manage more users if excessive connection is essential. Furthermore, using a SIC scheme, certain user's effecting may be harmed as a result of propagation errors. A boosted non-linear detection technique is necessary to overcome this propagation error. Due to inter-cell interference in PD-NOMA based on fairness, large power is allocated to weak users, who are often placed near the cell's edge. In the downlink NOMA network, these cell-edge users may generate increased inter-cell interference. Network management is a difficult problem to solve,[59] and the single cell setting may not be easily transferred to NOMA network.

To overcome this problem, we use a multi-cell setting, various interference cancellation approaches are necessary.

- **Applications of PD-NOMA:** The industrial uses of power domain-NOMA are highlighted in the following sections. Because of the interesting properties of it, this technique is used in a variety of upcoming radio systems. In March 2016, the 3GPP initiated research on 5G wireless systems. The MUST technique, also referred as NOMA, it is also recommended for 3GPP LTE-A technology. Without modifying the resource blocks of LTE-A,[60] two users may be supplied concurrently using the common subcarrier under the MUST technique. PD-NOMA has recently been successfully implemented to the next generation broadcasting standard in the United States, ATSC 3.0, it also termed as LDM technique.[61] The PD-NOMA technique is used to superimpose several streams to improve the spectral efficiency of digital television.

3.2 Pattern division multiple access (PDMA)

A MC-NOMA system is referred to as PDMA is suggested to fulfil the requirement for large connections in future 5G communications. In Refs. [62-64], PDMA may concurrently utilise resources in the frequency/time/space domains, which is suggested and further researched to increase the number of accessible users. In PDMA, a typical MC-NOMA technique, all the user could be multiplexed into different subcarriers. Furthermore, the same coded bits from one user are mapped onto the various subcarriers using phase rotation or power allocations strategies, that would improve the reliability, according to the modern receivers with MRC technique and variable sensing and belief propagation (BP).[65] Additionally, we can see that SCMA is a subset of PDMA. As the number of subcarriers assigned for every user is far less than three, PDMA degenerates into SCMA. User's data should be sparsely allocated into different subcarriers to reduce the complexity of the system. The following have been some of the benefits of PDMA:

- In the time/frequency/space/power domain, non-orthogonal signals superposition transmission allows PDMA to achieve higher multi-user multiplexing and diversity gain.
- Because the PDMA pattern matrix is generally sparse, low-complexity multi-user detection algorithms may be used to achieve high block error rate (BLER) performance.
- PDMA may simultaneously acquire coding gain as well as constellation shaping gain by using a hybrid proposed method with modulation and coding scheme.

3.3 Code domain-NOMA and its types

In traditional CDMA, several users can share a single channel at the same time. Separating users is accomplished by allocating unique codes, or spreading signatures, to each user. However, Inter-symbol-interference (ISI) in CDMA systems is inherent as a consequence with this channel sharing. Spreading codes with LDS and interleave sequences are used in CD-NOMA to overcome this issue. Signals are dispersed using low density signatures (LDS) in CD-NOMA,[66-68] that are mainly composed of sparse spreading codes with a minimal number of non-zero values respectively. Because the codes are sparse, more unique codewords may be generated for signal transmission, allowing more users to be non-orthogonally superimposed on a chip. Because N chips are required to build the spreading code, CDMA's major drawback is its bandwidth expansion. Using prior knowledge of the spreading codes, the signal is detected on the receiver side is then de-spreaded back to its original frequency. For this code domain NOMA, we evaluate the following three techniques depending on sparse spreading codes patterns.

- **Low-Density Spreading-CDMA:** A detailed study is presented about LDS-CDMA, which is a more advanced CDMA system.[69] Sparse spreading sequences are used instead of dense spreading sequences in this technique. There are only few non-zero spreading sequences in LDS CDMA than in traditional CDMA.[70] A SIC or a MPA based sequence detector would be exploited to accomplish MUD at the receiver. In MPA, a received symbol at each chip is called a factor node, while the transmitted symbol is called a variable node. The consistency of symbols is transferred across nodes, which improves error performance. The conversion from LDS-CDMA to LDS-OFDMA, for instance, may be done immediately by substituting the subcarriers in OFDM with chips.[71]
- **Low-Density Spreading (LDS)-OFDMA:** LDS-OFDMA, is a system that includes OFDM for multicarrier modulation and LDS for MA. FDMA benefits from frequency diversity as well as overloading due to its orthogonal mapping and sparse spreading. This permits a system's user capacity to increase while also lowering the ISI which might normally be connected with it. Signal spreading is accomplished using the same methods as LDS-CDMA, namely spreading, zero-padding, and interleaving. The superposed signal is modulated on a subcarrier belonging to the OFDM mapper, and each user's resultant chip is carried across it. But this flexibility comes at the cost of high receiver complexity, which is often costly.[72]
- **Sparse Code Multiple Access (SCMA):** SCMA is a novel NOMA method wherein coded bits are translated to multiplexed sparse codewords.[73-79] SCMA is an improved variant of LDS-CDMA proposed in Ref. [24], with minimal receiver complexity. SCMA uses non-orthogonal multi-user multiplexing to overflow transmitted symbols, allowing it to increase user capacity through low complexity MUD, reduced delay, and greater coverage, making it an effective solution for 5G multiple access. SCMA was introduced, which summarises the concept of LDS.[80] The QAM mapper and symbol spreader are merged into a single SCMA encoder in the SCMA system, that translates a collection of bits to multivariate complex field codewords. SCMA codeword signatures are sparse, similar to LDS, and may be characterized as a sparse factor graph. SCMA can outperform LDS with comparable decoding difficulty by precisely structuring the factor graph and

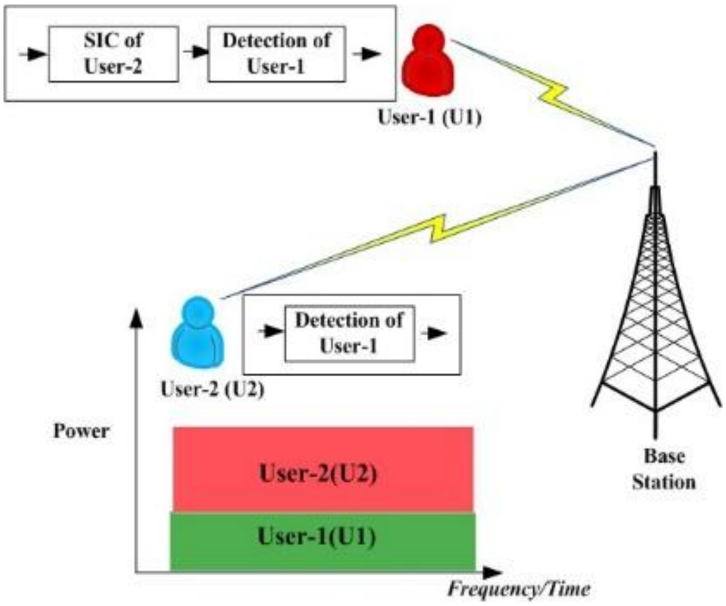

Fig. 4: Downlink PD-NOMA Architecture.

mapping algorithms.[81-83]

4. System model

The main idea of NOMA is to exploit power domain multiplexing at the transmitter(s) for signal combination, and SIC at receiver(s) for signal detection. NOMA can be realized in downlink or uplink as follows.

4.1 Downlink NOMA

An example of downlink NOMA transmission is shown in Fig. 4. Upon NOMA signaling, a BS broadcasts a signal mixture ($\sqrt{a_1 P_t} s_1 + \sqrt{a_2 P_t} s_2$) to user U_1 (who has a strong channel condition, referred to as the strong user) and U_2 (who has a weak channel condition, referred to as the weak user), where s_1 and s_2 are signals intended for the two users, and a_1 and a_2 are the corresponding power allocation coefficients with $a_1 + a_2 = 1$ and $a_1 < a_2$. At U_1, SIC is carried out to remove s_2 and then recover its own s_1. At U_2, its signal s_2 is decoded directly by treating s1 as interference. Consequently, the weak user (U_2) suffers interference from the other user, and the strong user (U_1) enjoys interference-free transmission. Now we generalize our discussions to N number of NOMA users to calculate its sum rate as follows. The transmitted signal for N number of NOMA users around the BS is given by Eq. (2) and it can be written as:[19]

$$s(t) = \sum_{n=1}^{N} \sqrt{a_n P_t}\, s_n(t) \tag{2}$$

where $s_n(t)$ is the individual information conveying OFDM waveform, a_n is the power allocation coefficient for the UE_k, and P_t is the total available power at the BS. The power allocated to each UE_k then becomes $P_n = a_n P_t$. The power is allocated according to the distance of UE_k to the BS, UE_1 is closest to the BS, so it is allocated with least power, whereas UE_K is the farthest one, therefore it has the highest power. The received signal at the UE_k as in Eq. (3).[19]

$$y_n(t) = s(t) h_k + n_k(t) \tag{3}$$

where h_k is the channel attenuation factor for the link between the BS and the UE_k, and n_k is the additive white Gaussian noise at the UE_k with mean zero and density N0 (W/Hz).Let us consider the farthest user first. The signal it decodes first will be its own signal since it is allocated the most power as compared the others. The signals for other users will be seen as interference. Therefore, the signal-to-noise ratio (SNR) for UE_K can be written as Eq. (4):[19,20]

$$SNR_N = \frac{P_N h_N^2}{N_o W + \sum_{i=1}^{N-1} P_i h_i^2} \tag{4}$$

where W is the transmission bandwidth. For the closest UE_1, the last signal it decodes will be its signal. Assuming perfect cancellation, the SNR for UE_1 becomes Eq. (5):

$$SNR_1 = \frac{P_1 h_1^2}{N_o W} \tag{5}$$

when NOMA is used, the throughput (in bps) for each UE_k can be written as Eq. (6):

$$R_N = W\, log_2(1 + SNR) = W\, log_2\left(1 + \frac{P_N h_N^2}{N + \sum_{i=1}^{N-1} P_i h_i^2}\right) \tag{6}$$

3.2 Uplink NOMA

In uplink NOMA transmission, shown in the right side of Fig. 5, usually a control message containing information of power allocation should be sent by the BS at the initial stage.[21] Then U_1 (with a strong channel condition, referred to as the strong user) and U_2 (with a weak channel condition, referred to as the weak user) transmit desired signals s_1 and s_2 to the BS using different power levels a_1 and a_2, respectively. On receiving these signals, SIC is carried out at the BS, and an optimal detection ordering would be to decode starting from the stronger signal first and moving toward the weaker signal. It is preferable to have distinct received power strength for SIC

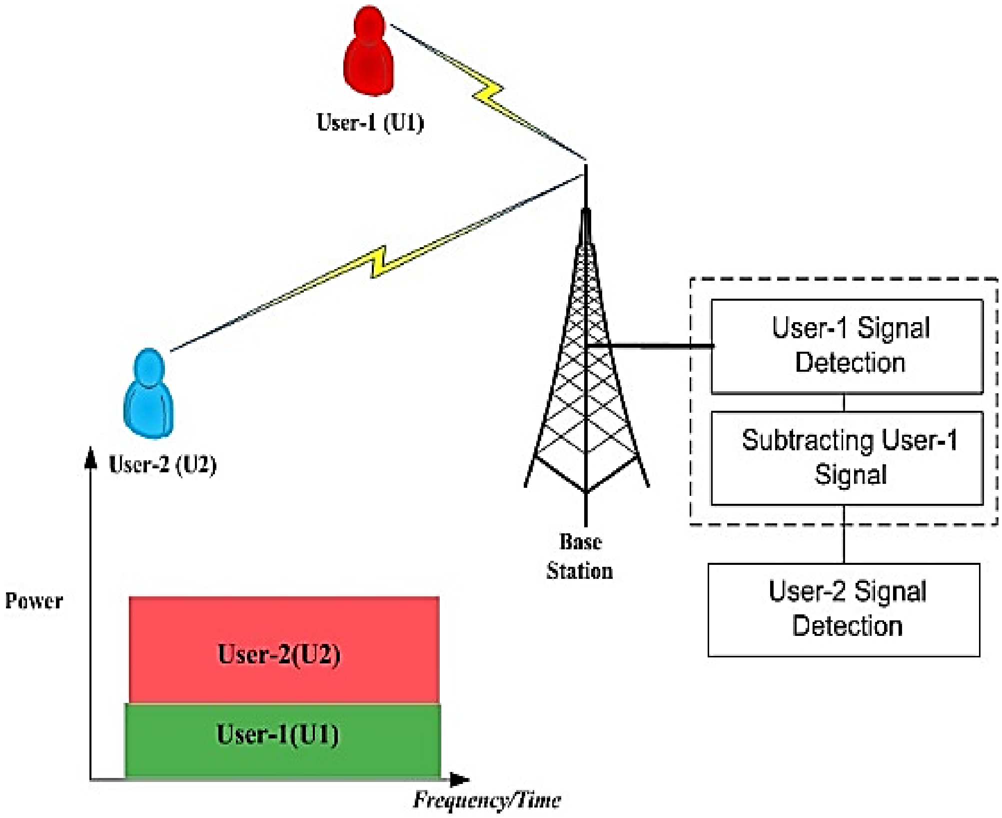

Fig. 5: Uplink PD-NOMA architecture.

processing, and thus, we choose $a_1 > a_2$ in uplink NOMA so that the BS first decodes s_1 and then cancels it to recover s_2. Therefore, the U_2enjoys interference-free transmission while the U_1 observes interference. In the uplink, the received signal at the BS that includes N number of NOMA user signals can be written as Eq. (7):[19]

$$y_n(t) = \sum_{n=1}^{N} s_n(t) h_n + n(t) \tag{7}$$

where h_n is the channel attenuation gain for the link between the BS and the UE_k, $s_n(t)$ is the information waveform for the kth UE, and $n(t)$ is the additive white Gaussian noise at the BS with mean zero and density N_0 (W/Hz). In the uplink, the UEs may again optimize their transmit powers according to their locations as in the downlink. However, here we assume that the users are well distributed in the cell coverage, and the received power levels from different users are already well separated. This assumption is more natural from a practical point of view, since power optimization requires connection between all the UEs which may be difficult to implement. At the receiver, the BS implements SIC. The first signal it decodes will be the signal from the nearest user. The SNR for the signal for the UE_1 can be written as, including others as interference in Eqs. (8) and (9):

$$\left(\frac{S}{N}\right)_1 = \frac{Ph_1^2}{N+\sum_{i=2}^{N} Ph_i^2} \tag{8}$$

$$R_1 = W\, log_2\left(1 + \frac{Ph_1^2}{N+\sum_{i=2}^{N} Ph_i^2}\right) \tag{9}$$

where P is the transmission power of UEs and $N = N_0 W$.The last signal that the BS decodes is the signal for the farthest user UE_K. Assuming perfect cancellation, theSNR for UE_K can be written as Eq. (10):[19]

$$\left(\frac{S}{N}\right)_N = \frac{P}{N} h_N^2 \tag{10}$$

Generally, for the k^th UE, the SNR becomes Eq. (11),

$$\left(\frac{S}{N}\right)_N = \frac{Ph_N^2}{N+\sum_{i=n+1}^{N} Ph_i^2} \tag{11}$$

The throughput (bps) for each UE can be written as Eq. (12):[19]

$$R_N = W\, log_2\left(1 + \frac{Ph_N^2}{N+\sum_{i=n+1}^{N} Ph_i^2}\right) \tag{12}$$

5. Other NOMA networks

The telecom industry has recognized NOMA as an exciting innovation with many benefits. Among these are improved quality of service, reduced latency, better connection, and increased SE. It also integrates well with other technologies like cognitive radio and multiplex multiplexing. NOMA plays a crucial role in enabling 5G networks to meet various performance standards, including fairness, throughput, dependability, and more. NOMA maximizes network efficiency by serving numerous customers efficiently using a shared resource block.[84,86] Research into the framework's potential uses and improvements is continuous, and it has already sparked the creation of numerous 5G multiple access systems.[4,87]

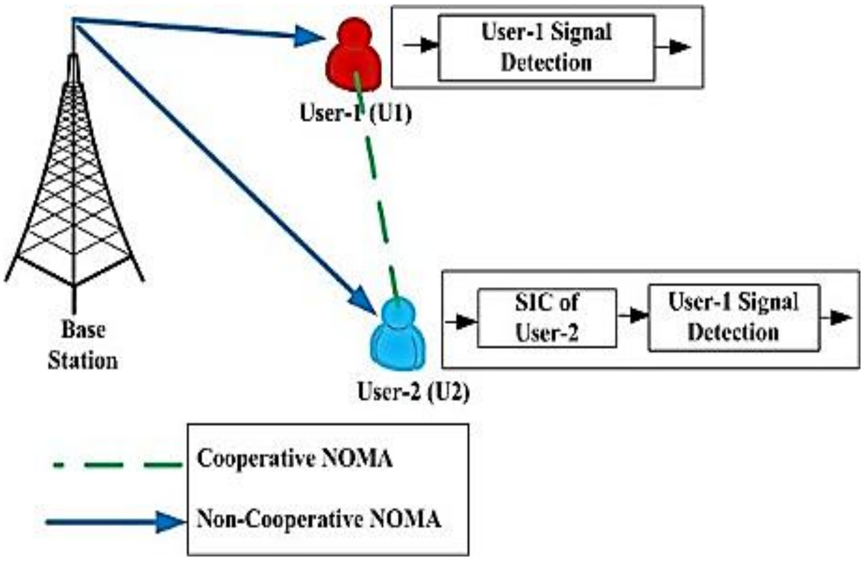

Fig. 6: Illustration of cooperative and non-cooperative NOMA.

5.1 Cooperative-NOMA (C-NOMA)

The cooperative NOMA (C-NOMA) paradigm is discussed in this section, and two forms of collaboration are discussed. As illustrated in Fig. 6, where one user acts as a replay to other user, this is called collaboration among users and it could be the primary goal of cooperative NOMA.[103] The following factors inspire this sort of cooperative NOMA:

- NOMA systems include redundant data that may be used for collaborative communication. A good illustration is that two user downlink scenarios. Before decoding its own signal, the strong user must decode the data of the weak user where the strong user can help the weak user by acting like a normal relay.
- In NOMA systems, there is indeed a requirement for cooperative communications. As an example, consider example 1 from Section 4. The weak user, User 1, has a rate of $\log_2$, which is badly influenced by the strong user's co-channel interference. The data rate of a weak user can be improved using cooperative communications.

Cooperative NOMA based architecture, and its user cooperation has been presented.[89] We propose a two-stage downlink transmitting scenario in which cooperative NOMA communication is conducted in two stages. The BS transmits a superimposed combination of the user's signals during the first stage. The stronger user acts as a relay in the second stage, delivers the weak user's message to the weak user across short-range transmission methods like Wi-Fi or Bluetooth. Also, demonstrated in Ref. [4] that cooperative NOMA outperforms cooperative OMA even when short-range communications are not employed. The rationale for this is because if short-range communications are not employed, cooperative NOMA simply requires two time slots. Cooperative OMA, on the other hand, requires 3 different time slots: where two for delivering messages to both the users and other time slot is being spent for cooperation of strong user to the weak user. Full duplex relaying can increase the spectral efficiency of cooperative NOMA even further, as illustrated in Refs. [90-92]. The strong user gets signals from the BS and transmits relays at the same time in these works, thanks to full duplexing. Half-duplexing relaying has the drawback of requiring a designated time slot aimed at relay communication. It's important to mention that perhaps the idea of FD transmission may be used in non-cooperative NOMA networks and has been found to increase the spectral efficiency of both uplink and downlink systems.[93-97]

5.2 Cognitive radio-NOMA (CR-NOMA)

The integration of NOMA and CR can help future wireless technologies make better use of their spectrum. The two upcoming technologies for 5G wireless networks, namely NOMA and CR, which allow additional resourceful radio spectrum usage in the forthcoming. The merging of NOMA and CR into a holistic framework, called a cognitive-NOMA network, is investigated in this paper for more efficient spectrum sharing. Cognitive NOMA network ideas are well connected with 5G wireless network operational needs, such as higher spectral efficiency, enormous connection, reduced latency, and improved user fairness. A cooperative transmission mechanism is presented in Ref. [98] to take use of the CR-NOMA system's intrinsic geographical variety. The closed-form analytical findings demonstrate that when multiple secondary users join in relaying, the collaborative transfer method performs better, allowing for the greatest diversity order at the unlicensed users and a diversity order of two at the primary user. It is also recognized that cognitive radio can make the effective use of radio spectrum by serving as SUs that cognitively change their operational characteristics to opportunistically or collaboratively accessing a frequency band owned by Pus.[99,100] Novel CR network designs based on full-duplex, D2D, and MIMO have been investigated in order to increase spectrum efficiency by utilizing CR technology to serve upcoming applications. Current literature on the integration of CR with NOMA[101-108] has proven that it is possible to achieve 5G criteria of high throughput, enormous

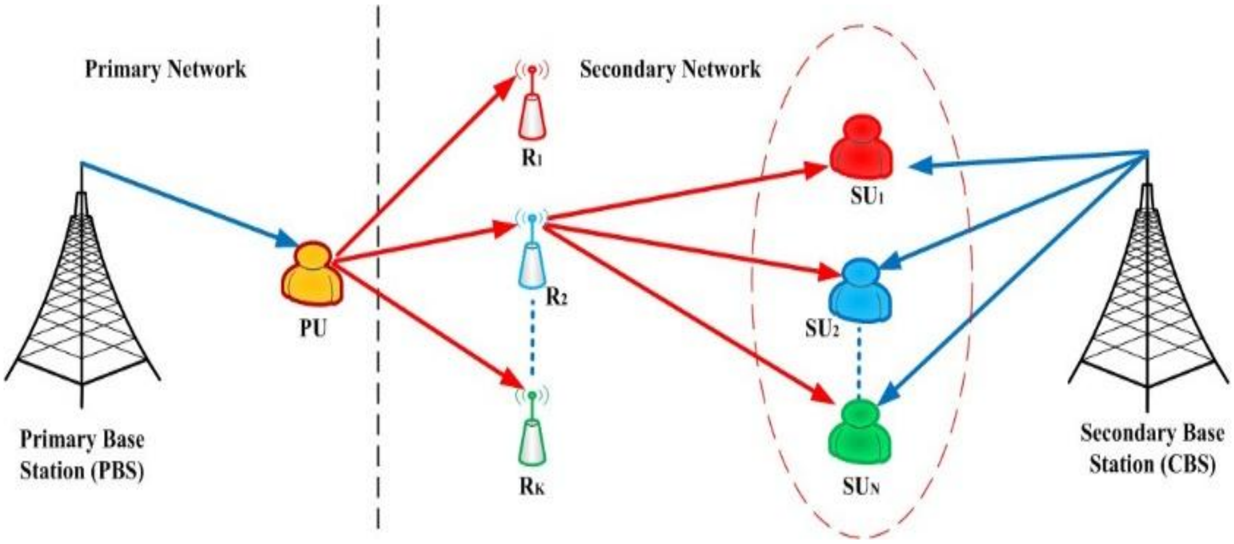

Fig. 7: Illustration of CR-NOMA.

connection, and low latency using this approach. Despite these potential advantages, implementing effective cognitive NOMA is a difficult task in reality. The presence of inter-network interference in between PU and SU nodes is worthwhile since CR and NOMA both have limited-interference, as well as intra-network interference induced by NOMA's power domain multiplexing, will almost certainly result in a severe degradation of reception reliability.[109-113] As a result, to limit interference and effectively utilise the underlying available spectrum, it is required to integrate NOMA and CR in an accurate way.

To accomplish more intelligent spectrum sharing, we combine NOMA capabilities with CR principles in this paper. We begin by providing a brief overview of the NOMA and CR paradigms, as well as the motives for cognitive NOMA and cooperative tactics to increase performance. Then we go through the basic operational principles of three different cognitive NOMA designs: underlay, overlay, and CR-based NOMA networks. It's worth noticing that both CR and NOMA are interference restricted, that may jeopardise reception. To solve this kind of difficulty, we suggest a cooperative relaying technique for each cognitive NOMA architecture to improve dependability. Because research into cognitive NOMA networks is still in its early stages, various possible obstacles in this subject are also discussed, many of which are intriguing directions for future study. Finally, we will say a few words about this article's conclusion.

As shown in Fig. 7, this research explores an underlay cognitive radio structure in which a cognitive user (or SU) opportunistically accesses the all the available free channels of a licensed user (or PU) without making any harmful interference. The primary network consists of a primary BS and a PU, which is provided with a single antenna system. The secondary network, on the other hand, uses NOMA, with the SBS serving N secondary users, indicated as SU_1, SU_2, ... SU_N, each with a single antenna. The amplify-and-forward (AF) relaying technique is used to deliver data between the PBS and N SUs via K relays. The SBS and relays are subjected to transmit power limits in order to preserve a reasonable level of interference and enable reliable communication for the core network. Because of the power limits, one relay is chosen to convey the information to N SUs in order to reduce interference to the primary user. The decision method relies on the characteristics of the connection among SBS and relays, where relay with the stronger connection being chosen. Although this provisional technique is non ideal, it motivates substantially to update the investigation that follows.[115-120]

CR Architectures: One of CR's primary goals is to accomplish dynamic spectrum access by periodically monitoring about its surroundings and modifying its operational settings. Hence, we have three types of CR architectures:[114]

- Underlay CR networks: Simultaneous PU and SU transmissions are permitted as long as the PU interference is kept to a manageable level.
- Overlay CR networks: SU can offer relaying provisions to the PU and simultaneously sends their own signals.
- Interweave: A SU can transmit its own signals in the absence of PU only.

If the interference created by non-cognitive users is below a certain level, the underlying paradigm permits cognitive users to operate. The underlying paradigm includes strategies that allow the cognitive radio to communicate, providing it is alert of the interference generated by its transmitter to each PU receiver. Cognitive radio is commonly known to as a secondary user in this context, as it cannot seriously disrupt the transmission of current (usually licensed) users, who really are known to as primary users. The underlying paradigm specifies that simultaneous non-cognitive and cognitive communications are only permitted if the cognitive devices interference at non-cognitive receivers is below a certain level. The PU interference limit must be overcome by employing multiple antennas to direct CR users which are apart from PBS, or by employing a larger bandwidth on which the CR can spreads under the noise level, later de-spread at the CR receiver. In overlay systems, cognitive radios utilise complex signal processing and coding to preserve or enhance non-cognitive radio's communication but simultaneously gaining some more bandwidth with their own transmission. Cognitive transmitters have awareness of the non-cognitive user's codebooks and messages, which is the underlying assumption for overlay systems. If non-cognitive users adopt a standardized norm for network based on a publicised codebook, for example, the codebook knowledge might be acquired. They might also broadcast their codebooks on a regular basis. Decoding the message at the cognitive receiver could yield a non-cognitive user message.

The overlay model, on the other hand, posits that the cognitive transmitter knows about the non-cognitive message before the non-cognitive user starts transmitting it. But this is unrealistic for an original broadcast, it is reasonable for a message resend in which the cognitive user hears and decodes the first transmission while the intended recipient is unable to do so owing to fading or interference. However, the non-cognitive user might transmit their message to the cognitive user (who is supposed to be nearby) before sending it out. Knowing a non-cognitive user's message and codebook can be used in a number of ways to reduce/cancel the interference between cognitive and non-cognitive receivers. The cognitive radios in IoT systems make use of spectrum voids to transmit without interfering with other communications. The original impetus for cognitive radio was the interweave paradigm,[1] which is based on the notion of opportunistic transmission. After research by the FCC and industry revealed that a large portion of the bandwidth is underutilized almost all of the while, the notion was born.[2,20] In other words, there are temporary spatial temporal frequency gaps, referred to as spectrum holes, in both licensed and unlicensed bands that are not in regular use. These gaps alter with time and place, and cognitive users can make use of them for communication. As a result, opportunistic frequency reuse over spectrum gaps improves spectrum usage. The interweave approach necessitates awareness of the non-cognitive (unlicensed) users on the spectrum's activity data. One might alternatively assume that all users in a frequency band are cognitive, but occupied users are designated as PUs, while other users are identified as SUs who never interfere with existing user interactions.

5.3 mm-Wave massive MIMO-NOMA

MIMO technology seems to be another 5G technology that has been proposed. Further, integrating MIMO and NOMA technologies in 5G helps to maximize the capacity of the system, which was among the most important concerns in 5G. This MIMO-NOMA pairing can however increase the spectral efficiency of the system.[121,122] MIMO and NOMA integrating with multi-cellular systems were extended by the researchers in Ref. [123]. Developing NOMA to multi-cellularity results in intercell interference at the CN's boundary, lowering the QoS for individuals at the cell's boundary. Lowering QoS in boundary cellular degrades the user fairness. Massive MIMO is suggested to offer ample spectrum diversity.[124] Massive MIMO (mMIMO) technology includes a high number of antennas at both the base station as well as at the users. One of the most difficult issues involved in mMIMO is achieving the optimal use of such diversity while keeping costs reasonable. In addition, providing CSI in the BS is among the most key aspects of mMIMO deployment as shown in Fig. 8.[125,126] As a result, the CSI errors might have a significant impact on mMIMO system. Radio frequency (RF) calibration errors, channel variations, and channel estimation errors were all factors that affected CSI. The further latest technique in 5G wireless systems is millimeter-wave (mm-wave) technique and due to its larger bandwidth, would increase spectral efficiency (SE) and therefore maximize the system's achievable throughput and user capacity. Generally, 30-300

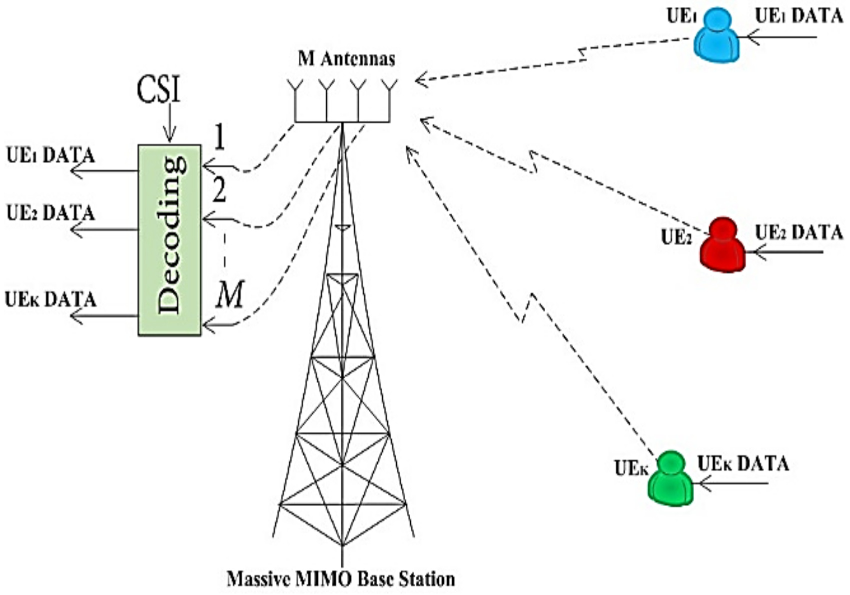

Fig. 8: Illustration of mMIMO-NOMA.

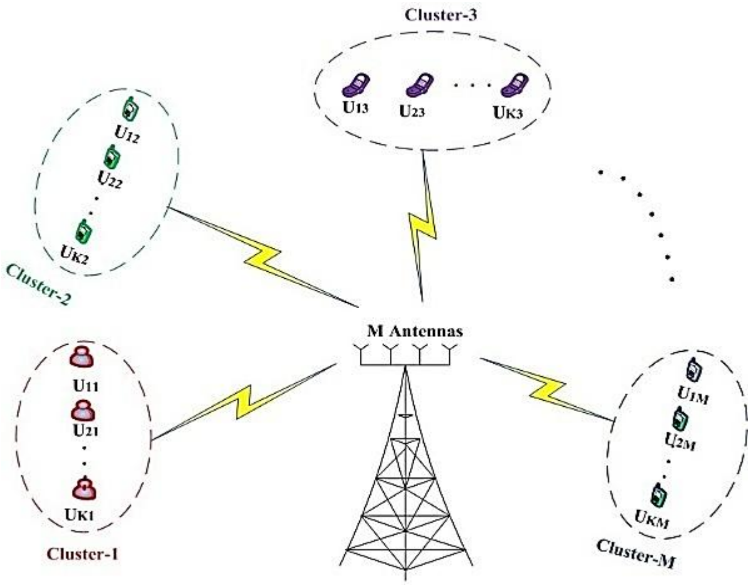

Fig. 9: Illustration of clustering-based mm-wave mMIMO-NOMA.

GHz frequency range is commonly known as the mm-wave frequency band. Because of their high frequency and short propagation distance, mm-waves and present microwaves have differing transmission properties. As a result, several investigations on transmission properties and channel models in the mm-wave propagation system have already been studied.[127-131]

Fig. 9 shows, that the clustering-based mm-wave mMIMO-NOMA scheme, which has garnered a lot of interest in recent years. The overall performance evaluation of the mm-wave MIMO-NOMA propagation scheme is presented.[132,133] The researchers propose a cooperative mm-wave MIMO NOMA multicast approach to improve the performance of the system.[134-136] The transmitting system achievement of mm-wave NOMA is also being studied,[137] taking into account the increased directivity of the mm-wave propagation method. The total sum rate, system capacity, and BER are measured in systems that are combined with both the MIMO and NOMA techniques, analyzed, and presented in the Log-normal and Rayleigh fading channel.[138] The cooperative NOMA for mm-wave vehicular communications at crossing roads is suggested.[139] The research team used cooperative NOMA to develop closed-form outage probability expressions and contrasted them to cooperative OMA. The coverage probability of mm-wave cooperative NOMA relay selection methods is presented,[135] and it is proven that nearest and nearest relay preferences outperform OMA. The researchers have presented mm-wave MIMO-NOMA transmissions,[137] which uses one prominent link for such mm-wave channels.

Beginning with 5G, mm-wave mMIMO is a reliable and suitable technique for seeking innovative possibilities in upcoming cellular networks. It derives out of an amalgamation of greater antenna gains (feasible with mMIMO antenna arrays) and broad usable spectrum (especially mm-wave frequencies). mm-wave massive MIMO is allowed to surpass free from current technological burdens, meet the issues of powerfully rising smartphones lead to the growth, and bring new possibilities for future developments, due to improved SE and EE, high precision, density, versatility, and overall network strength. Although distinct transmit-receive antenna combinations exhibit independently fading coefficients, utmost advantages can really be accomplished in mm-wave mMIMO networks. Whenever the antenna element separation is at minimum 0.5λ, and λ seems to be the electromagnetic wavelengths, this would be possible. Because λ decreases with increasing carrier frequency, mm-wave frequency may accommodate a greater number of elements in antenna arrays of the same physical aspect at microwave frequencies. The existence of correct CSI is required to get this maximum efficiency.[140-143] The size of antenna arrays (as well as the inter-antenna separation) gets very tiny at mm-wave bands. As a result, a great number of antenna elements can be packed into a physically limited space, allowing for a vast MIMO antenna array not only at the base station as well as at the user equipment.[143,144] The highest number of antennas allowed by 3GPP (for example, at 70 GHz) is 1024 for the BSs and 64 for the user equipment, correspondingly. In terms of RF chains, the large number for base station and user equipment are 32 and 8, accordingly.[145,146]

5.4 CR-MIMO-NOMA

MIMO-NOMA is a research topic that aims to improve spectral and energy efficiency. CR-based NOMA is another field of study. Improvements in spectral efficiency, energy efficiency, and other factors are required for 5G and the aforementioned methodologies. We can employ MIMO, CR, and NOMA all at the same time to make spectrum, energy, and other resources more efficient. This will be the next generation of communication research. MIMO-NOMA systems are recently investigated, and it's been proven that they surpass MIMO-based OMA approaches in terms of spectral efficiency.[147] Multiple access techniques like TDMA/FDMA

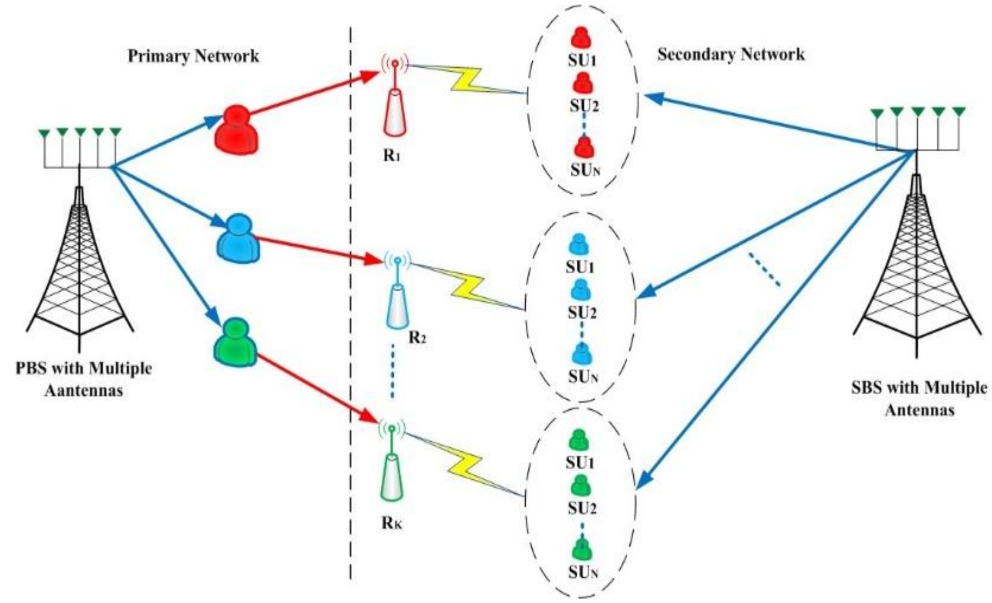

Fig. 10: Illustration of CR-MIMO-NOMA.

are utilised in a typical CR network to support numerous SUs in a unoccupied bands of PUs. A MIMO-NOMA system with multiple transmits and receive antennas, on the other hand, has been used for spectrum management in a CR network to achieve mammoth connectivity and improve spectral efficiency.

Fig. 10 shows that, a basic MIMO-NOMA based CRN, as there exits two BS along K number of relay networks which are connected to K clusters and each cluster consists of N number of secondary users. Assume that the primary BS and secondary BS has N users with multiple antennas.[148,149] The researchers have been investigated the performance of MIMO-NOMA based CRN in terms of its spectral efficiency, where considering imperfect sensing.[150,151] In spectrum sensing method, the CR network uses traditional energy detectors. Novel formulations for the improved spectral efficiency of CR based MIMO-NOMA networks were also produced, taking into account all of the spectrum sensing technique's results. Also analysed the spectrum efficiency of MIMO-NOMA based CRN along with MIMO-OMA based CR networks using Monte Carlo simulations and numerical approaches, and found that MIMO-NOMA CRN had a better spectral efficiency than MIMO-OMA CRN.[152-155]

5.5 Secure beamforming-based NOMA networks

There are three Different cases on MIMO-NOMA-based secure beamforming techniques are discussed in this subsection, with the aid of Fig. 11, and features as well.[156,157]

- **Internal Privacy Leakage:** As per the SIC scheme, the users with weaker channel gains are more likely to be leaked

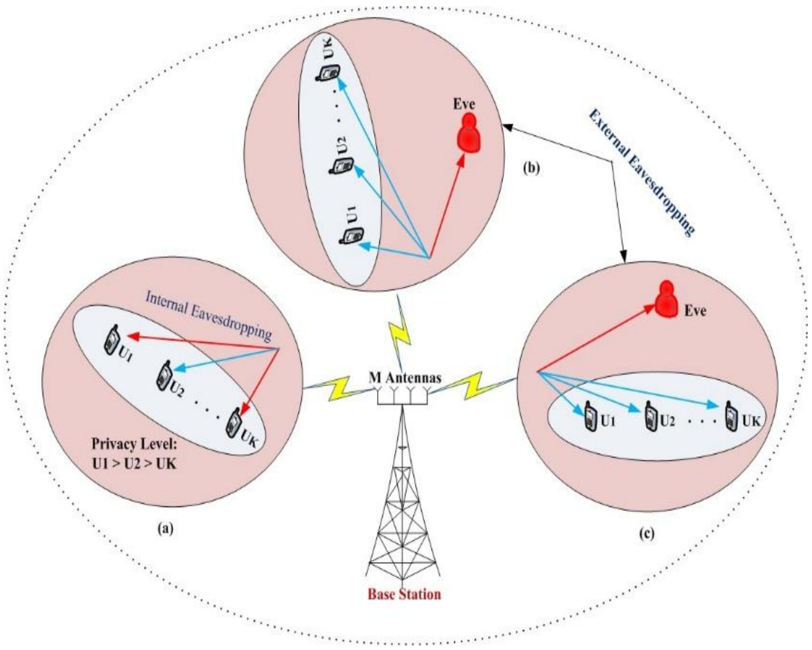

Fig. 11: Illustration of mMIMO-NOMA networks with secure-beamforming.

at the stronger users, since the weaker user's signals with higher power will be recovered and cancelled at the strong receiver, in traditional NOMA networks. As a result, the privacy of users having poor channel gains is jeopardized. The strong user UK seems to have the maximum priority, while the weak user U_1 does have the least priorities, which is depicted in Fig. 11a. To combat internal eavesdropping, a control scheme relying on beamforming optimizations could be used to decrease the leakage of an individual NOMA user.

- **External Eavesdropping with CSI:** External Eavesdropping with CSI: As illustrated in Fig. 11b, we investigate the scenario where the eavesdropping CSI is accessible for the authorized network. This is fair in instances when the eavesdroppers are network authorized users but not permitted to acquire private data. Under this situation, as per the standard SIC receiver order requirements with regard to the transmission beamforming scheme, we may effectively optimize the sum secrecy rate of all authorized personnel.
- **External Eavesdropping without CSI:** In the scenario, artificial noise (AN) and inter-user interference (IUI) are employed to improve security without eavesdropping CSI, these are the two main approaches to disturb the eavesdropping. When the transmit power of the BS is high enough as shown in Fig. 11c, AN can be utilized to degrade the eavesdropping performance without affecting the legitimate transmission via beamforming optimization. On the other hand, IUI can be leveraged to assist the secure transmission when the wireless resource is inadequate as shown in Fig. 11b. In this case, the beamforming design combined with the modified SIC order can provide novel insights for improving the security of a specific user. Following that, different secure transmitting strategies based on beamforming optimizing for the above-mentioned circumstances would be described in NOMA systems in depth. Because of its SC in NOMA systems, so every user can receive the messages of all other users from the BS, and stronger users with good channel conditions must decode and subtract the messages of weaker users from the signals before analysing their own, resulting in private information, as depicted in Fig. 11. As a result, throughout this part, beamforming with power allocation is used to ensure the security of a specified private user while taking into account SIC.[158]

5.6 Hybrid beamforming for mm-wave massive MIMO-NOMA

The users in the same cluster utilize the same beam, whereas users in other clusters employ various beams in the mm-wave MIMO-NOMA networks. The large power variation in the same beam could ensure optimal SIC performance among users in the same cluster. The various distinctive beams are favorable for dissimilar clusters to significantly lower the inter-cluster inference.[159-161] As a result, mm-wave MIMO-NOMA can efficiently increase spectral efficiency while also dealing with larger connectivity requirement. In the perspective of the mm-wave MIMO-NOMA networks,[160] investigates the maximum sum rate of the suggested beamspace MIMO-NOMA in a particular mm-wave channel state, indicating a significant improvement in performance over the conventional beamspace MIMO. In the beamspace, zero-forcing beamforming (ZFBF) is used to minimize interbeam interference. Moreover, to maximize the possible sum rate, a PA is suggested, that includes intra-beam and inter-beam power optimization. The author introduces a combined analog/digital beamforming technique with a powerful method based aimed at optimizing EE.[161] A cluster is formed by users who have a strong channel correlation and a strong channel gain differential. The optimization of the network's sum rate for clusters of multiple users is investigated in [162] It divides the main analysis into two parts: power allocation and beam gain allocation. Almasi offers a hybrid beamforming approach to maximize the sum rate and investigates the impact of beam imbalance on its performance.

Mostly all present mm-wave MIMO-NOMA studies,[161-163] had also considered perfect CSI knowledge at the transmit side, which is challenging to achieve in practice. The authors presented a hybrid precoding approach that relies on one-stage feedback that exploits the 2nd channel conditions to prevent multiuser interference and utilizes the feedback delay to allow exact beam knowledge.[164] Arbitrary beamforming is a technique wherein the BS transmits random beams and users having sufficient transmit power return respective CQI towards the BS.[137] The mm-wave MIMO-NOMA technology featuring limited feedback was already investigated, however, the results may vary from system to system. User clustering and intracluster interference cancellation is given minimal feedback have still not been addressed.[164] The feedback delay is reduced by using arbitrary beamforming technique, but channel measuring is time-consuming and tricky.[137] Throughout this research, we propose an integrated solution for such mm-Wave MIMO-NOMA networks with poor CSI.

5.7 Space division multiple access (SDMA)

SDMA is expected to play a crucial role in future wireless networks, including advanced 5G and beyond-5G systems. Here are some potential applications and benefits of SDMA in future wireless networks:

- **Increased Capacity:** SDMA enables multiple users to simultaneously transmit and receive data using spatial resources. This enhances the capacity of the wireless network by exploiting the spatial dimension. With the deployment of multiple antennas at the transmitter and receiver, more users can be accommodated within the same frequency band, leading to increased network capacity.
- **Improved Network Performance:** SDMA allows for efficient utilization of the available spectrum by enabling spatial multiplexing. By transmitting multiple data streams in parallel over different spatial channels, SDMA enhances the SE of the system. This results in higher data rates, improved SE and overall network performance.
- **Enhanced Coverage and Reliability:** SDMA can help

overcome coverage challenges in future wireless networks. By employing beamforming techniques, where the transmitted signal is focused towards the intended user, SDMA can improve the signal quality and extend coverage range. This is particularly beneficial in areas with weak signal strength or in environments with obstacles that cause signal degradation.

- **Multi-User MIMO:** SDMA is closely related to multi-user MIMO (MU-MIMO) technology. MU-MIMO, enabled by SDMA, allows multiple users to simultaneously transmit or receive data over the same frequency band using spatial multiplexing. This enables better utilization of available resources and improves the overall network capacity and user experience. Overall, SDMA holds great promise for future wireless networks by addressing the challenges of increasing capacity, SE, coverage, and interference mitigation. Its deployment in advanced wireless communication standards will enable the support of a larger number of connected devices, higher data rates, and improved QoS in diverse deployment scenarios.

5.8 Rate splitting multiple access (RSMA)

A possible physical layer transmission paradigm for non-orthogonal transmission, interference management, and MA techniques in 6G, RSMA is based on the idea of rate-splitting (RS). When compared to the extreme interference management tactics used by SDMA and NOMA, RSMA divides user messages into common and private sections, allowing for partial decoding of the interference and partial treatment of the interference as noise. RSMA's adaptability means it works well regardless of the intensity of the interference. Automatically switching between SDMA and NOMA by adjusting the transmit power and data in the shared and private channels, RSMA adapts to the interference level. In addition to soft switching, RSMA also supports hard switching between SDMA and NOMA,[165] we utilize a toy scenario with two users sharing a single radio resource and an M-antennas transmitter to highlight the distinctions between the aforementioned MA schemes. In OMA, only one user (user-1) is given access to the available radio bandwidth at any given time. At the transmitter, SDMA uses linear precoding to separate the two user messages into separate streams. Direct decoding occurs because each user disregards any remaining interference from the other stream as noise. In NOMA, each user's messages are transmitted in a separate stream that is then superimposed at the transmitter. Both users must decode the information coming from the second user. In RSMA, the sender divides each user's message W_k into a shared section ($W_{c,k}$) and a private section ($W_{p,k}$), and then merges the shared sections ($W_{c,1}$, $W_{c,2}$) into a single shared section (W_c). At the transmitter, the three messages W_c, Wp,1, and Wp,2 is individually encoded and linearly pre-coded from W1 and W2. The shared stream s_c is decoded first, with all private streams disregarded as noise. Each user decodes their own intended private stream s_k by disregarding the remaining user's private stream as noise once the common stream has been removed from the received signal. By decoding some of the interference with the common stream decoding and treating some of it as noise with the intended private stream decoding at every user, dynamic interference management is made possible. RSMA is reduced to SDMA when the common stream (s_c) is disabled in a way that causes W_k to be encoded straight into the private stream (s_k), and all interference between s_1 and s_2 is regarded as noise.[166] When s_2 is disabled, W_2 is encoded into s_c, and W_1 is encoded into s_1, as shown in Fig. 1.[166] RSMA is reduced to NOMA. Thus, RSMA is a viable physical layer transmission paradigm for non-orthogonal transmission, interference management, and multi-user communications since it unifies the existing MA methods. Next, we will dive into the primary physical layer issues faced by today's MA schemes, and the reasons why it's so important to incorporate this new paradigm into the planning and construction of tomorrow's wireless systems.

However, the RSMA is an advanced multiple access technique that has been proposed for future wireless networks, including 5G and beyond-5G systems. RSMA offers several benefits and capabilities that can significantly enhance the performance of wireless communication networks.[167-173] Here's an overview of RSMA and its potential applications:

Efficient Spectrum Utilization: RSMA enables the simultaneous transmission of multiple data streams by splitting the available resources into common and private components. This allows users to share the same frequency band efficiently while achieving higher spectral efficiency. By exploiting the broadcast nature of wireless channels, RSMA optimally allocates resources and improves the overall network capacity.

- **User Fairness and Quality of Service (QoS):** RSMA provides a flexible framework for managing the trade-off between user fairness and QoS. The rate splitting functionality allows the allocation of different rates and power levels to individual users based on their channel conditions and quality requirements. This enables better fairness among users with varying channel conditions and diverse QoS requirements.
- **Interference Management:** RSMA offers improved interference management capabilities. By splitting the resources into common and private components, RSMA allows the base station to carefully design the transmit signals, taking into account interference conditions. This enables better control over interference levels and enhances the network's overall performance, especially in dense deployment scenarios.
- **Advanced Multi-User MIMO:** RSMA is closely related to MU-MIMO technology. It provides a powerful framework for MUMIMO transmission schemes by allowing the joint processing of multiple user's signals at the base station. RSMA can leverage the benefits of MU-MIMO to achieve higher spectral efficiency, increased network capacity, and improved user experience.
- **Future Network Evolution:** RSMA offers a flexible and scalable solution for future network evolution. It can be

combined with other advanced techniques such as beamforming, NOMA, and network slicing to provide even greater gains in terms of capacity, coverage, and reliability. RSMA's versatility makes it suitable for various deployment scenarios, including ultra-dense networks, internet of things (IoT) applications, and mission-critical communications. RSMA is still an emerging concept, and its implementation in practical wireless systems is an active area of research and standardization. It holds significant potential to address the challenges posed by future wireless networks, enabling higher capacity, improved spectral efficiency, better interference management, and enhanced user fairness and QoS.

5.9 Simultaneous wireless information and power transfer (SWIPT)

SWIPT is considered a promising technology for future wireless networks, including 5G and beyond. SWIPT offers several potential benefits and applications that can enhance the performance and stability of wireless communication systems.[174-181] Here's an overview of how SWIPT can be relevant for future wireless networks.

- **Energy Efficiency:** SWIPT can significantly improve the energy efficiency of wireless networks. By allowing wireless devices to harvest energy from the received signals, SWIPT reduces the reliance on traditional power sources and batteries. This can extend the battery life of devices and enable sustainable operation in energy-constrained environments. In future networks, where the number of connected devices is expected to increase exponentially, SWIPT can help reduce energy consumption and enhance overall network efficiency.
- **IoT Applications:** SWIPT is particularly well-suited for IoT applications. Many IoT devices are low-power and require long battery life or even perpetual operation. SWIPT enables these devices to simultaneously receive data and power, eliminating the need for frequent battery replacements or wired connections. This is crucial for applications like smart sensors, wearable devices, and other IoT endpoints, where reducing maintenance costs and achieving long-term autonomy are important goals.
- **Wireless Charging Infrastructure:** SWIPT can drive the development of wireless charging infrastructure in future networks. By integrating SWIPT capabilities into access points or base stations, wireless charging hotspots can be established, allowing devices to wirelessly charge while maintaining communication. This can be beneficial for public spaces, homes, offices, and other areas where wireless charging convenience is desired. The deployment of SWIPT-enabled charging infrastructure can facilitate the widespread adoption of wireless charging and eliminate the need for multiple charging cables and adapters.
- **Hybrid Energy Systems:** SWIPT can be integrated into hybrid energy systems, combining multiple energy sources to power wireless devices. For example, SWIPT can work in tandem with renewable energy sources like solar panels or wind turbines to charge devices and ensure continuous operation even when primary energy sources are unavailable. This hybrid approach enhances the reliability and sustainability of wireless networks, especially in remote or off-grid locations.
- **Over-the-Air Energy Transfer:** SWIPT enables over-the-air energy transfer, eliminating the need for physical connections between devices and power sources. This can have significant implications for future wireless networks, enabling novel applications such as drone charging in-flight, wirelessly powered sensor networks, or wireless energy transfer to moving vehicles. Over-the-air energy transfer provides greater flexibility and convenience in powering various wireless devices, promoting a more interconnected and autonomous ecosystem. SWIPT is an area of ongoing research and development, with various challenges to address, including optimizing power efficiency, ensuring reliable power transfer, and managing potential interference. However, its potential to enhance energy efficiency, enable IoT applications, facilitate wireless charging, and support hybrid energy systems makes SWIPT a promising technology for future wireless networks.

5.10 Physical layer security (PLS)

PLS is a concept that focuses on exploiting the physical characteristics of wireless communication channels to enhance the security of data transmission. PLS aims to provide secure communication by leveraging the properties of the wireless channel itself, making it an important consideration for future wireless networks.[182-189]

Channel characteristics for security: PLS takes advantage of the unique characteristics of wireless channels, such as fading, noise, and multipath propagation, to establish secure communication links. By carefully designing the transmission scheme and exploiting these channel properties, PLS techniques aim to make it difficult for eavesdroppers to intercept or decode transmitted data, even if they can receive the signals.

- **Physical Layer Key Generation:** PLS can employ physical layer techniques to generate secret keys between communicating parties. For example, wireless channel characteristics can be used to establish a secret key shared by the transmitter and intended receiver, ensuring secure communication. These physical layer key generation methods offer advantages such as secure key establishment, resistance to key management vulnerabilities, and enabling secure communication without relying solely on cryptographic algorithms.
- **Wireless Jamming and Interference:** PLS techniques can mitigate wireless jamming and interference attacks by exploiting the inherent properties of the wireless channel. For instance, intentional interference can be detected through channel measurements, and adaptive transmission strategies can be employed to minimize its impact on the legitimate communication link. This helps enhance the resilience and security of wireless networks against jamming and

interference attacks.

- **Diversity and Beamforming:** PLS can leverage diversity techniques and beamforming to enhance security. Multiple antennas at the transmitter and receiver can be utilized to create multiple communication paths, making it challenging for eavesdroppers to intercept the transmitted data. Beamforming allows the transmitter to focus the signal towards the intended receiver, thereby reducing the potential for interception by unintended receivers or eavesdroppers.
- **Securing Internet of Things (IoT) Networks:** PLS is particularly relevant for securing IoT networks. As IoT devices often operate with resource constraints, PLS techniques that exploit physical layer characteristics can provide a lightweight and efficient security solution. PLS can help protect IoT devices from eavesdropping, unauthorized access, and data tampering, thereby ensuring the confidentiality and integrity of IoT communications.
- **Future Wireless Networks:** As wireless networks evolve to support higher data rates, increased device density, and diverse applications, the importance of PLS is expected to grow. PLS can address security challenges in emerging technologies such as 5G, 6G, and beyond, where massive connectivity, ultra-low latency, and high reliability are key requirements. PLS techniques will play a crucial role in securing these networks, safeguarding user data, and protecting against evolving security threats. PLS is an active area of research, and ongoing efforts are focused on developing robust PLS algorithms, exploring new physical layer security mechanisms, and integrating PLS into standard wireless communication protocols. By leveraging the unique characteristics of the wireless channel, PLS offers a promising approach to enhancing security in future wireless networks.

5.11 Unmanned aerial vehicle (UAV)

UAVs, also known as drones, have gained significant attention for their potential applications in various fields, including wireless networks.[190-196] UAVs can serve as flying base stations or aerial relays, extending the coverage and capacity of wireless networks in remote areas, disaster-stricken regions, or crowded events.

Coverage and Connectivity: UAVs can be equipped with wireless communication equipment to provide coverage in areas where traditional infrastructure is limited or unavailable. They can act as temporary or mobile base stations, extending the reach of wireless networks to underserved regions or during emergencies. UAVs can establish wireless connectivity between ground users or act as relays to enhance network performance.

- **Deployment Flexibility:** UAVs offer the advantage of rapid deployment and flexibility in positioning. They can be quickly deployed to specific locations based on demand or network requirements. This adaptability makes them suitable for providing temporary connectivity in emergency situations, at large events, or for supporting infrastructure repair and maintenance activities.
- **Network Planning and Optimization:** UAVs can aid in optimizing network coverage and capacity by collecting data and performing network planning tasks. They can be equipped with sensors and software tools to analyze signal strength, interference levels, and user distribution, enabling network operators to optimize their infrastructure placement and resource allocation strategies.
- **Backhaul Connectivity:** UAVs can act as mobile backhaul nodes, connecting remote areas with the core network infrastructure. By establishing wireless links between UAVs and ground base stations, they enable data transfer between disconnected regions and the internet backbone. This capability is particularly useful in remote areas, disaster scenarios, or for providing connectivity in temporary setups.
- **Autonomous Operation:** UAVs can operate autonomously using artificial intelligence and onboard sensors. They can perform tasks such as self-optimization, adaptive networking, and intelligent routing, allowing for efficient use of network resources. Autonomous UAVs can adapt to dynamic network conditions and make decisions in real-time, enhancing the reliability and performance of wireless networks.
- **Challenges and Considerations:** Deploying UAVs in wireless networks comes with several challenges. These include regulatory constraints, such as airspace regulations and spectrum allocation, ensuring secure and reliable communication links, managing power and battery constraints for prolonged operation, and addressing potential privacy concerns. Additionally, network coordination and integration with existing infrastructure need to be carefully planned to avoid interference or disruptions.

Overall, UAVs have the potential to revolutionize wireless networks by extending coverage, improving connectivity, and enabling rapid deployment in various scenarios. Continued advancements in UAV technology, coupled with regulatory frameworks and network integration strategies, will play a crucial role in realizing their full potential in future wireless networks.

5.12 Vehicle-to-everything (V2X)

V2X communication refers to the exchange of information between vehicles and other entities, including infrastructure, pedestrians, cyclists, and other vehicles. V2X is a crucial component of future wireless networks, enabling advanced connectivity and intelligent transportation systems.[197-204]

- **V2X Communication Technologies:** V2X encompasses various communication technologies, including Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), Vehicle-to-Pedestrian (V2P), and Vehicle-to-Cloud (V2C) communication. These technologies enable vehicles to exchange real-time information, such as location, speed, acceleration, traffic conditions, road hazards, and more. Future wireless networks will play a vital role in providing the connectivity and bandwidth required for efficient and reliable V2X communication.

- **Enhanced Safety and Efficiency:** V2X communication contributes to improved road safety and traffic efficiency. By enabling vehicles to share information, such as collision warnings, emergency braking alerts, and traffic signal status, V2X helps prevent accidents and reduces congestion. Future wireless networks will need to support low-latency and reliable communication to ensure timely delivery of critical safety-related messages.
- **Cooperative Maneuvers and Autonomous Driving:** V2X communication is instrumental in enabling cooperative maneuvers and facilitating autonomous driving. Vehicles can share their intentions, such as lane changes, merging, or overtaking, with nearby vehicles and infrastructure. This coordination enhances the safety and efficiency of maneuvers, especially in complex traffic scenarios. Future wireless networks will need to provide robust and low-latency communication to support the coordination and decision-making required for cooperative and autonomous driving.
- **Traffic Management and Optimization:** V2X communication enables real-time traffic monitoring and management. Vehicles can provide information about traffic flow, congestion, and road conditions, allowing transportation authorities to optimize traffic signal timings and develop adaptive traffic management strategies. Future wireless networks will support the exchange of large volumes of data between vehicles, infrastructure, and central traffic management systems, enabling effective traffic control and optimization.
- **Connectivity with Smart Cities:** V2X communication is an integral part of smart city initiatives. By integrating V2X capabilities into urban infrastructure, such as traffic lights, road signs, and parking systems, cities can create an interconnected ecosystem for intelligent transportation. Future wireless networks will play a vital role in providing the connectivity and bandwidth required for seamless communication between vehicles and smart city infrastructure.
- **Electrification and Energy Management:** V2X communication can facilitate the integration of electric vehicles (EVs) into the energy grid. EVs can communicate with the grid to optimize charging schedules, participate in demand-response programs, and provide grid stabilization services through vehicle-to-grid (V2G) communication. Future wireless networks will support the secure and reliable communication between EVs and energy infrastructure, enabling efficient energy management and the integration of renewable energy sources.

V2X communication is expected to revolutionize transportation and create safer, more efficient, and sustainable mobility systems. Future wireless networks will need to provide robust, low-latency, and secure connectivity to support the diverse requirements of V2X applications, ensuring the reliable exchange of information between vehicles, infrastructure, and other entities.

6. NOMA-based wireless networks

Vehicle-to- The preceding part gave an overview of the NOMA and the fundamental principles that underpin it. With this background in mind, the purpose of this section is to demonstrate how NOMA may be used to various types of wireless networks. More specifically, we will examine the application of NOMA to CN, D2D transmission, and WSN in light of recent work.

6.1 Cellular networks (CN)

A cellular network may be categorized into four groups from both a theoretical and practical perspective. SCST, SCMT, MCST, and MCMT CNs are the four types of CNs. As a result, the following discussion covers the application of NOMA to the aforementioned CN classes in depth. Figures also show several kinds of NOMA-based cellular networks for better clarification.[208-211]

- As illustrated in Fig. 12, in a SCST cellular network, where a one BS communicates with numerous users using the NOMA concept. The SIC approach is used at the receiver side to decode the signal while minimising multiuser interference.[33] This setup creates a single-cell network system, wherein individuals are generally spread randomly within the BS transmission range.
- NOMA-based SCMT CNs are comparatively understudied in the present research. The topic of resource allocation is investigated in Ref. [212] for NOMA-based single cell heterogeneous (multi-tier) channels. Only small-cell BSs employ the NOMA protocol to interact with their customers in the model under consideration. The researchers designed a many-to-one matching game principle for resource allocation challenges to maximise the sum-rate of small-cell BS. Finally, they have suggested a newly dispersed approach for obtaining the stated game's result.
- NOMA-based MCST CNs have received relatively little attention in the current research. The authors look into uplink NOMA for large-scale mobile networks.[213]A homogeneous PPP is used to simulate the geographical positions of the BSs. PCP models the geographic topology of users by using the locations of BSs as a parent PP, with users concentrated around the locations of BSs. This encapsulates the relationship between user position and BS.

6.2 Device-to-device (D2D) communications

Transmission-based divesting solutions based on D2D transmissions which includes the necessary characteristics: First, the operator has full control over D2D communications, which include end user and D2D relay transmit power, transmit time slot, bandwidth resources, and so on; second, D2D communications use the same bandwidth resources as cellular transmissions for better spectral efficiency, as shown in Fig. 13. Thus, inter- and intra-cell interference control are key concerns.[22,214-219] Moreover, D2D communications can also be carried out in an unlicensed spectrum band, like an industrial, scientific, and medical radio channel, or in the same licensed band as cellular users. While cell phone users use the unlicensed band, such as the WLANs frequency band (2.4 and 5 GHz for Wi-Fi or IEEE 802.11 wireless standard) and the IEEE 802.16 WiMAX frequency band (2.5 GHz, 3.5 GHz, 5.8 GHz, *etc*.), the information exchange process is very similar to that in classic ad hoc mobile networks if the cellular operators are not involved.

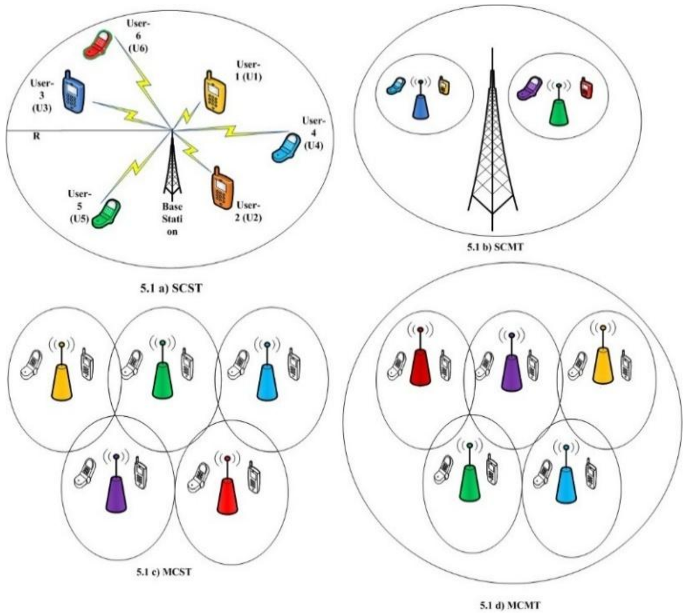

Fig. 12: Application of NOMA in CN.

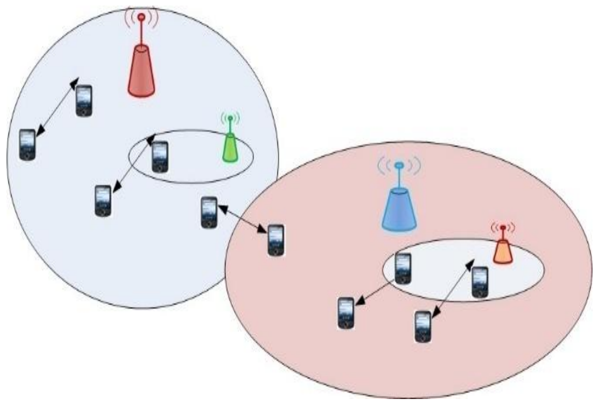

Fig. 13: Application of NOMA in D2D Communications.

6.3 Wireless sensor networks (WSN)

The use of NOMA-based WSN for smart agriculture systems is examined.[220] The suggested relay-aided NOMA-based system outperforms the traditional OMA schemes for WSN in agriculture, according to the findings. The authors examined a NOMA based WSN, with time-switching and power allocation based relaying protocols have been suggested to employ energy harvesting.[221] WSN are one of the IoT research fields that both academia and industry are interested in WSNs. WSNs are made up of sensor nodes (SNs) that gather data from their surroundings and interact with one another as well as with the BS.[222-224] Consider the WSN depicted in Fig. 14, in which sensors and sink nodes are spread at random throughout the 2D-plane. Other CT nodes coexist in the WSN under review since WSNs frequently exist in a license-free band, as illustrated in Fig. 14. Consider that every sink node (SIN) is located at the centre of each disc with a radius of RSINK, which represents the sink node's coverage. Furthermore, the sink node uses NOMA broadcasts to communicate with many SNs.

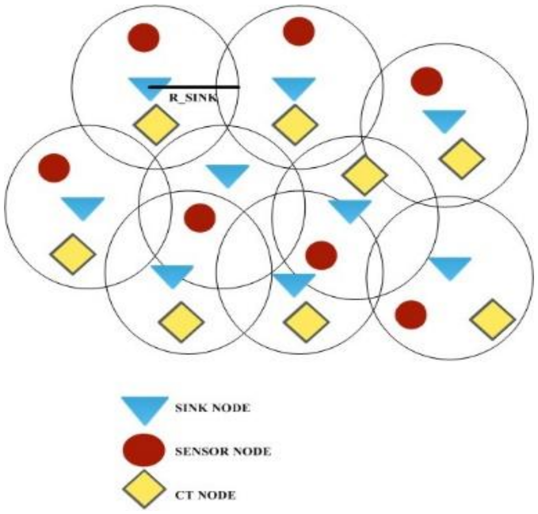

Fig. 14: Application of NOMA in WSN.

6.4 Application of artificial intelligence and machine learning in wireless communication

Wireless communication using artificial intelligence and machine learning techniques offers several applications that enhance the performance, efficiency, and user experience of wireless networks. Here are some notable applications of artificial intelligence and machine learning (AI/ML) in wireless communication:

- **Signal Processing and Optimization:** AI/ML algorithms can be employed to improve signal processing tasks, such as channel estimation, interference mitigation, and equalization. These techniques enable more accurate signal detection and decoding, leading to enhanced overall network performance.
- **Spectrum Management:** AI/ML can assist in dynamic spectrum management by predicting and optimizing spectrum allocation based on real-time demand. Machine learning models can analyse historical data, user behavior, and network conditions to predict spectrum availability and dynamically allocate frequencies, improving spectral efficiency.
- **Resource Allocation and Traffic Management:** AI/ML algorithms can optimize resource allocation in wireless networks, including power, bandwidth, and routing decisions. By learning from network dynamics and traffic patterns, these algorithms can allocate resources efficiently, improve network capacity, and mitigate congestion. Network Planning and Deployment: AI/ML can aid in network planning and deployment by analysing geographical data, user density, and coverage requirements. Machine learning models can assist in determining the optimal placement of base stations, antenna configurations, and network parameters, resulting in improved coverage and reduced deployment costs.
- **Quality of Service Optimization:** AI/ML techniques can

optimize QoS by dynamically adapting network parameters based on real-time conditions. These algorithms can prioritize traffic, allocate resources accordingly, and mitigate network bottlenecks, ensuring a consistent and reliable user experience.

- **Predictive Maintenance and Fault Detection:** AI/ML models can analyse network performance data to detect potential faults, anomalies, or performance degradation. By proactively identifying issues, network operators can undertake predictive maintenance activities, reduce downtime and improving network reliability.
- **User Behaviour and Experience Analysis:** AI/ML can analyse user behaviour, preferences, and context to personalize services and enhance user experience. By understanding user patterns, AI/ML algorithms can optimize content delivery, predict user demands, and provide tailored recommendations.
- **Security and Intrusion Detection:** AI/ML can contribute to wireless network security by identifying malicious activities, detecting intrusion attempts, and mitigating cyber security threats. Machine learning algorithms can analyse network traffic patterns, identify anomalies, and proactively respond to potential security breaches.

These are just a few examples of how AI/ML can be applied to wireless communication to improve network performance, optimize resource allocation, enhance user experience, and ensure network security. Continued advancements in AI/ML techniques and their integration with wireless communication systems will undoubtedly lead to further innovations in this field.

7. Future research directions

In this part, we highlight various potential problems and future research objectives for establishing cognitive NOMA networks, the majority of which are also extremely applicable to collaborative CR-NOMA.[4]

- **Interference Control:** The intelligence of NOMA systems is still relatively interference limited. For example, in NOMA underlay networks, in which secondary receivers (SR) experience either intra- or inter-network interference, which is produced by PD multiplexing and primary transmission. Furthermore, the overall interference measured at a primary receiver (PR) should be limited by a measurable amount. As a result, interference control is crucial in the development of cognitive NOMA networks. Inter-network interference can be mitigated using techniques similar to those used in traditional wireless systems, namely interference arrangement and common transceiver beamforming. Furthermore, power distribution must be wisely planned to reduce the harmful effect of intra-network interference.
- **Imperfect CSI:** The majority of current cognitive NOMA research is built on the statement that ample CSI is accessible. In practise, however, channel estimate errors, mobility, and feedback latency result in inaccurate CSI, possibly lowering system performance. Imperfect CSI causes an incorrect power allocation at the secondary transmitter (ST) in underlay NOMA networks, error propagation at the secondary receivers and increased primary receiver's interference are the major results. Moreover, a relay might be incorrectly picked using a delayed form of CSI in cooperative NOMA and cooperative overlay NOMA networks, resulting in poor performance for both networks because of a diversity order loss. Novel transmission architectures for cognitive NOMA systems that are resistant to CSI mistakes should be developed as a result.
- **Energy Efficiency:** Upcoming wireless systems must be likely to be green, while consuming relatively little energy.[225,226] Several recent studies have looked at spectrum efficiency and reliability. However, the subject of energy efficiency maximisation in CR-NOMA networks has yet to be researched. Furthermore, overlay NOMA networks can use simultaneous wireless information and power transfer, secondary transmitter harvests energy/information from the primary transmitter, then utilises the collected energy to service the primary receiver and secondary receivers concurrently utilising NOMA signalling, obtaining combined energy/spectrum efficiency. Where, the trade-off between energy and spectrum efficiency is a key parameter for assessing overall network performance. As a result, effective resource provision method designs are more than required.
- **CR-NOMA with Multi-Carriers:** Interweave network, which may be thought of as a CR based NOMA architecture with multi-carriers, is alternative viable model for CR-NOMA networks. To be more specific, all cognitive users are first separated into many clusters. Using spectrum sensing, the CRs in every cluster is then assisted with NOMA signals in the equivalent resource blocks that have been identified as accessible, and for effective communication, various clusters are assigned to diverse orthogonal resource blocks. In order to improve network speed and user fairness, appropriate resource allocation algorithms must be developed. However, because spectrum detection, user grouping, and subcarrier or power allotment are all intertwined, this appears to be a difficult task that requires additional investigation.
- **Cognitive MIMO-NOMA:** As spatial diversity is utilised, the introduction of MIMO to NOMA can provide significant performance advantages,[227] and this gain is likely to be preserved with the expansion to cognitive MIMO-NOMA. However, creating effective cognitive MIMO-NOMA networks is a difficult challenge. User ordering is difficult in downlink MIMO-NOMA underlay networks, for example, because one is the user's channels are characterized by matrices or vectors (in contrast to the SISO method), and the other is that users can suffer with several types of inter-network interference, which is also characterized by a matrices or a vectors. User with different power allocation is the best way, with the goal of limiting interference to the PU and improving the secondary network's sum rate. Combined pair of transmitter-receiver based beamforming is one way to do, but it comes at a cost of greater complexity.
- **User Ordering/Relay Selection:** As previously stated that, cooperative relaying has shown its capability to increase

receiver efficiency in CR-NOMA systems. As soon as there are several SUs and relays available, user ordering/relay selection is a simple and effective way to take advantage of multiuser diversity. Traditional relay selection and user ordering approaches are focused on the coordination of a single receiver, and hence it may not be easily used to CR-NOMA networks, where the receipt dependability of several NOMA aided SUs/PUs must be assured simultaneously. For future CR-NOMA systems, it stimulates the development of enhanced relay selection/user planning.

- **Physical Layer Security:** For cognitive NOMA networks, physical layer security is a challenging task. Interference is a problem in cognitive NOMA networks, as previously established. Meanwhile, this is a major flaw that might be exploited by a DoS attack by sending destructive signals to NOMA-enabled SUs and interfering with SIC execution. Alternative security alarm for CR based NOMA networks is that a collaboration relay might be hacked. To put it another way, the untrustworthy relay is seeking to eavesdrop on the secret data in order to benefit from it. To prevent information leakage, a method called cooperative jamming under physical layer security can be used.
- **Hybrid Multiple Access (HMA):** Because of the prevalence of intra-user interference, NOMA systems require SC and are thus intrinsically interference restricted. Accordingly, in lower SNR case, the performance advantage of NOMA over traditional OMA is restricted.[23] As a result, the NOMA scheme in its purest version does not appear to be especially suited for wireless systems with low SNRs (IoT, D2D, M2M systems, *etc*). To address this issue, a hybrid multiple access related to a mix of OMA and NOMA might be developed, ease of switching between OMA and NOMA process while maximising optimal network throughput.
- **Full-Duplex (FD):** The full duplex approach has the prospective to increase spectral efficiency by concurrently sending and receiving across the same frequency channel. Integration of full duplex-based NOMA transmission might be a viable method for increasing total system capacity intending to fulfil the challenging expectations of future wireless networks. Some attempts to investigate NOMA-based FD networks have been done in recent research, for a fast reference.[228-231] Self-interference and intra-user interference, alternatively, hinder the execution of NOMA and full duplex, respectively. As a result, in order to implement NOMA-assisted full duplex networks, a competent low-complexity receiver plan must be necessary. Improved resource and power allocation algorithms may also be required, with the goal of decreasing self-and intra- user interference while increasing the system's total sum-rate. As a result, looking into NOMA-assisted FD networks and associated difficulties might be an interesting future study topic.
- **Semi-Grant Free (SGF)-NOMA:** The authors have investigated the secrecy performance of semi-grant-free (SGF) systems that are based on NOMA and permit grant-free users to share resources with grant-based users while maintaining service quality for the latter.[232-234] First, the study focuses on scenarios with a single grant-free user and produces analytical formulas for the exact and asymptotic secrecy outage probability (SOP) of NOMA-aided SGF systems.
- **AI and ML Solutions for 5G/B5G systems:** The 5G/B5G systems face challenges in methods struggle with non-convex problems, relying on expert knowledge and manual parameter tuning. These methods have high computational complexity and are sensitive to initialized parameters. Recent advances in AI and ML offer opportunities to overcome these challenges. The article proposes a novel downlink cluster-free NOMA framework for ultra-flexible SIC operations. The article investigates ML methods for autonomous learning of high-efficiency communication designs. Two ML paradigms are proposed for efficient SIC and beamforming design in single-cell and multi-cell networks.[235-241]

▪ A new cluster-free NOMA framework is introduced for efficient communication in single cell and multi-cell networks.

▪ Dedicated beamforming vectors enable simultaneous transmission to multiple users.

▪ Flexible SIC operations are made possible without the need for predefined user clusters.

▪ A binary indicator controls interference elimination through SIC.

▪ This framework encompasses existing SDMA, BB-NOMA, and CB-NOMA schemes, offering a unified approach.

▪ Adaptive SIC design optimizes system performance by dynamically adjusting to user channel correlations.

- **Machine Learning Solutions for 5G/B5G systems:**

▪ Next-generation wireless systems require solving complex, high-complexity, coupled, and non-convex mixed-integer nonlinear programming (MINLP) problems.

▪ Machine learning solutions are investigated to circumvent the limitations of conventional convex optimization methods.

▪ Deep neural networks (DNNs) can be trained to approximate optimal solutions to challenging optimization problems.

▪ AI can learn high-quality solutions in a data-driven manner, avoiding the need for expert knowledge and manual parameter initialization.

▪ Learning-based solutions can reduce computational complexity and achieve fast time response and automated control.

▪ Unsupervised learning, deep reinforcement learning (DRL), and automated machine learning (AutoML) methods are explored due to the limitations of supervised learning.

- **Unsupervised Learning:** Supervised learning seeks to match predefined solutions, whereas unsupervised learning optimizes model parameters by minimizing loss functions without needing labeled data. In wireless communications, two widely used machine learning models are the multi-layer perceptron (MLP) and the convolutional neural network (CNN). However, these models often underperform in this field because they were initially designed as black-box solutions for computer vision tasks. To better apply unsupervised learning in wireless communications and mitigate these issues, two specific approaches have been suggested.[238]

- **Deep Unfolding:** Deep unfolding introduces a novel learning approach that integrates domain knowledge and optimization theory into the learning process. The primary concept is to transform the iterative optimization algorithm into a layer-wise learning model. This method approximates the iterative optimization pattern, converting black-box deep neural networks (DNNs) into trainable white-box models that offer both theoretical interpretability and learning capabilities. As a result, this approach enhances performance, reduces the number of training parameters, and accelerates convergence.[239,240]
- **Graph Neural Networks:** Graph neural networks (GNNs) introduce a novel structural learning approach, capturing the intricate relationships and interdependencies between wireless nodes. By leveraging message passing, GNNs learn structural features from graph data, enabling distributed inference and significantly enhancing scalability and generalization capabilities in unsupervised learning. This leads to efficient coordination in distributed wireless communication designs, outperforming traditional non-structural DNNs.[241]
- **Deep Reinforcement Learning:** Reinforcement learning is often used for long-term optimization problems that can be framed as a Markov decision process (MDP). In this context, each BS acts as an independent agent that interacts with its environment to improve decision-making through trial and error. By observing the system state at each time slot, it determines the optimization variables (actions) to maximize the accumulated discounted reward. Deep reinforcement learning (DRL) combines deep learning with reinforcement learning, employing DNNs for function approximation in high-dimensional state spaces. Specifically, a deep Q-network (DQN) learns to estimate the Q-value based on the Bellman equation, allowing for greedy action selection.[242] While DQN is effective for discrete control, deep deterministic policy gradient (DDPG) has been developed for continuous control using the actor-critic framework.[243] DDPG trains an actor to map states to continuous actions deterministically and uses a critic to estimate the Q-value function. For multi-cell distributed communication systems modeled as a decentralized partially observable MDP (Dec-POMDP), DQN can be extended to a multiagent variant where each agent performs Q-learning independently using local observations. However, this approach creates a non-stationary environment for each agent, violating Markov assumptions and hindering Q-learning convergence. To address this, multi-agent deep deterministic policy gradient (MADDPG) has been proposed,[244] utilizing centralized training with distributed execution. MADDPG trains multiple distributed actors with a centralized critic to ensure robust coordination.
- **Automated Machine Learning:** Next-generation wireless systems demand adaptive learning models that can swiftly respond to diverse scenarios. To achieve this, the integration of Automated Machine Learning (AutoML) with ML-based communication design is crucial. Auto ML enables automatic configuration of learning models, minimizing human intervention and enhancing performance. Auto ML comprises three key techniques: hyperparameter tuning, neural architecture optimization, and meta learning.[245] These techniques allow for automatic optimization of hyperparameters and neural architecture, as well as learning a generalizable initial model that can quickly adapt to new, unseen communication scenarios. By selectively adopting these AutoML techniques as add-on modules, NGMA communication systems can effectively cater to various application requirements.

Table 3: The authors contributions for different 5G/B5G systems (PART-1).

Category	Contribution	Reference
OMA and NOMA	-The limitations, benefits, and research direction prospects for NOMA development are addressed to give investigators in this domain insights further into a possible new study.	[4,5]
NOMA	-The recommended software-defined multiple access (SoDeMA) paradigm is capable of supporting a diverse range of benefits and solutions having various needs. -The NOMA is likely to play a key role in 5G wireless communications in the next.	[5-13]
SC	-The idea of SC has been presented and examined for the first time in the early works when it was offered as a technique of concurrently sending data on a single source to several receivers. -The various possible methods for adopting SC have been presented and explored by the researchers.	[35-42]
SIC	-An Intra-user interference can be lowered at the NOMA receiver using modern reception methods such as SIC.	[39,40]
Imperfect SIC	-The performance of a SIC detector is tested once the decoding ordering of the recipient doesn't really match the output signals. -A tree search method and SIC strategies featuring low-complexity power control have been given throughout this study.	[43-49]
Imperfect CSI	-The authors have presented an innovative mm-Wave MIMO-NOMA system featuring restricted feedback. Using minimal feedback CSI, a low-complexity user clustering technique, and a hybrid beamforming method were developed.	[17, 50]

Category	Contribution	Reference
PD-NOMA	-This paper offers a thorough description of cooperative downlink networks based on PD-NOMA control (PD-CNOMA networks). -The various past studies have already been published to show the advantages and applicability of PD-CNOMA systems for wireless communication.	[34,55,56]
PDMA	-The PDMA technique uses a combined transmitter and receiver architecture to provide low-complexity SIC-based MUD with significantly better performance than traditional OMA schemes.	[62-64]
CD-NOMA	-Different CD-NOMA systems (LDS-CDMA, LDS-OFDM and SCMA) are investigated and compared to existing OMA methods. -Each scheme performance is assessed by evaluating its BER and Outage Probability (OP) and modeling these across an AWGN environment with multiple SNR values.	[37-38]
LDS-CDMA	-The information-theoretic study is used to compute the capacity region of the LDS- Multiple Access Channel (LDS-MAC).	[69]
LDS-OFDM	-The writers of this research looked at the potential advantages of employing the MC-LDS-based MA technique as a multiple access mechanism for next-generation cellular systems. -The performance of LDS-OFDM over a multipath fading environment is analyzed and compared, in which LDS-OFDM excels comparable to well-known multiple access schemes such as MC-CDMA or MC-LDS-CDMA systems.	[71-72]
SCMA	-The suggested approach using two iterations achieves BER results that are very close to conventional MUD schemes involving six iterations, however with significantly less complexity.	[73-83]
C-NOMA	-In the C-NOMA system, an OP and diversity order are investigated, as well as a user pairing-based method is presented to minimize system complexity. -The recommended FD C-NOMA network delivers improved ergodic capacity in the low to moderate SNR range and better outage probability for both users.	[90-92,103]

Table 4: The Authors' contributions for different 5G/B5G systems (PART-2).

Category	Contribution	Reference
CR-NOMA	The resource allocation (RA) challenge is offered in, as well as CR optimization algorithms and a detailed examination of the RA problem formulations. - The difficulties of spectrum assignment are examined, with particular attention paid to dynamic spectrum allocation, spectrum aggregation, and spectrum mobility. - A unique NOMA-based collaborative activity involved in the spectrum-sharing CRN was presented. - The authors have investigated NOMA in large-scale underlay CRN with randomly generated users. ToimprovethesystemgapsacrossNOMAandtraditionalMAinCRNbyoptimizing the power allocation parameters.	[99,101,106]
mm-Wave Massive MIMO-NOMA	The CSI reception problems of mm-Wave massive MIMO were addressed. - How and where to obtain analog-digital beamforming using a hybrid analog-digital antenna design also was investigated. - The performance of NOMA-based communications in mm Wave communication networks via Fluctuating two-ray (FTR) pathways is analyzed in terms of outage probability and ergodic capacity.	[121-146]
CR-MIMO-NOMA	-This article has joint benefits of CR, NOMA, and MIMO cellular technologies to offeraspectralandinterference-efficientmodelcalledtheMIMO-basedCR-NOMA.	[150-155]
Secure beamforming-based NOMA	To protect the privacy of the individual user, we initially studied the internal privacy leakage problem and created two secure beamforming algorithms. - The cumulative secrecy rate is again optimized by optimizing precoding sequences using eavesdropping CSI, taking external eavesdropping into consideration.	[156,157]

Category	Contribution	Reference
Hybrid beamforming-based mm-Wave m-MIMO-NOMA	The downlink of a single-cell mm-Wave communication network has also been implemented using hybrid beamforming (HB)-based NOMA. To investigate an HB-NOMA user's possible rate, an optimizing issue for the sum rate of all users in the cell was already developed, or even an algorithm based on the strongest user pre-coder design was given to address it in three stages.	[136,159,163]
SDMA/RSMA	-RSMA automatically reduces to SDMA or NOMA by tuning the powers and contents of the common and private streams when the interference is weak/strong. RSMA naturally bridges SDMA and NOMA, including any hard switching between SDMA and NOMA.	[165-173]
SWIPT	-SWIPT offers several potential benefits and applications that can enhance the performance and stainability of wireless communication systems.	[174-181]
PLS	-PLS aims to provide secure communication by leveraging the properties of the wireless channel itself, making it an important consideration for future wireless networks	[182-189]
UAV	UAVs have the potential to revolutionize wireless networks by extending coverage, improving connectivity, and enabling rapid deployment in various scenarios. Continued advancements in future wireless networks.	[190-196]
V2X	-V2X is a crucial component of future wireless networks, enabling advanced connectivity and intelligent transportation systems	[197-204]
NOMA applied to Wireless Networks	-Moreover, there seems to be limited work that reviews the state-of-the-art utilization of NOMA in the framework of CNs, D2D communications, and WSNs.	[208-224]

As shown in Tables 3 and 4, we list the authors' contributions for different 5G/B5G systems (PART-1 and PART-2). We have gone through the essential concepts of NOMA in-depth, including SC and SIC methods. NOMA performance measures, such as SNR and throughput expressions, are also examined in this research. Also discussed are the difficulties in NOMA network systems in terms of perfect and imperfect SIC. To enable more intelligent spectrum sharing, NOMA capabilities are being integrated into CR and MIMO systems. We begin by providing a brief overview of the NOMA, MIMO, and CR paradigms, as well as the motives for inspired cognitive NOMA and cooperative tactics to increase performance. It is demonstrated that by employing future MIMO-based beamforming approaches, the performance of a CR-NOMA may be greatly enhanced. To conclude, this study examines a number of research challenges related to NOMA, SDMA, RSMA, SWIPT, PLS, UAV, V2XSGF-NOMA, AI/ML and DL based NOMA networks and suggests some future research extents. Finally, this study comprehensively examines various critical challenges associated with 5G/B5G application and suggests some future research directions. As a result, this survey gives the foundations of NOMA with other integrating systems for the current technology's findings.

8. Conclusion

In the core principle and possible features of the NOMA networks, that has stood accepted as an innovative associate of MA techniques, have been detailed in this study. The exertion of NOMA in CNs, D2D networks, and WSNs were thoroughly examined and explored. This research also emphasizes most of the important NOMA related framework difficulties, as well as some prospective future research topics. NOMA is widely regarded and expected to do a crucial part in emerging 5G/B5G wireless systems, with an ability to enable large connectivity and low latency. Furthermore, we went through the essential concepts of NOMA in depth, including SC and SIC methods. Also discussed, the difficulties in NOMA network systems in terms of perfect and imperfect SIC. To enable more intelligent spectrum sharing, NOMA capabilities are being integrated into CR models. We begin by providing a brief overview of the NOMA and CR paradigms, as well as the motives for cognitive NOMA and cooperative tactics to increase performance. It is demonstrated that employing MIMO approaches, the performance of a CR-NOMA may be greatly enhanced. Finally, this study examines a number of research challenges related to NOMA, SDMA, RSMA, SWIPT, PLS, UAV, and V2X networks and suggests some future research extents. As a result, this survey gives the foundations of 5G/B5G wireless networks for the future technology enhancements.

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Conflict of Interest

There is no conflict of interest.

Supporting Information

Not applicable.

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