Wireless Networks (2023) 29:1629–1653
https://doi.org/10.1007/s11276-022-03175-7

ORIGINAL PAPER

NOMA for 5G and beyond: literature review and novel trends

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Accepted: 14 October 2022 / Published online: 24 November 2022

Abstract

The non-orthogonal multiple access (NOMA) system is considered an important technology that enables the fifth-generation (5G) wireless systems and beyond to satisfy different requirements such as high efficiency, massive networks, sophisticated optimization, and steady quality. Also, the NOMA scheme provides advancements and attractive characteristics such as low latency, ultra-dense service, great fairness, innovative waveform architecture, efficient bandwidth utilization, and massive device connectivity compared to the earliest multiple access schemes. Therefore, the NOMA system necessitates an efficient resource allocation technique such as user pairing (UP) and power allocation (PA) schemes to achieve optimal performance. So, in this paper, we discuss the significance of resource allocation in NOMA in 5G networks and beyond in-depth. As a result, firstly, we review the classification of multiple access schemes, the various types of NOMA techniques, and the characteristics of NOMA. Then, the paper analyzes the issue of resource allocation by classifying the different resource allocation schemes in 5G. Further, a summary of the solutions to the current resource allocation issues are reviewed. Finally, we suggest future research challenges on which to focus.

Keywords NOMA · 5G · OMA · Resource allocation · User pairing · Power allocation

1 Introduction

Due to the potential increase of mobile connectivity, the rapid evolution of communications technologies, and the increasing demand for the upcoming latest services and facilities, for instance, the internet of things (IoT) and cloud-based architecture and design implementations, the fourth generation (4G) cellular system can no longer meet the actual requirements of users. A new generation of cellular technology, the fifth generation (5G), is emerging to improve the quality of services (QoS) and achieve user satisfaction [1]. The 5G wireless system is the most sophisticated technology available, capable of connecting the entire world without boundaries and satisfying global development and demand. The 5G technology offers many new advanced features that make it the most impressive technology. The features that distinguish the 5G technology and beyond are [1–6]:

- Enormous device connection and support for different QoS criteria (10^6 devices/km^2 with a variety of QoS standards).
- Higher mobile data volume per area.
- Reduced latency (1 ms for a roundtrip latency).
- Better availability and reliability.

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- Higher spectral efficiency (SE) and energy efficiency (EE).
- Reduction in network energy usage.
- Better coverage (100%).

Recently, many promising techniques have been substantially explored in recent decades to realize the features of the 5G cellular system and beyond. These promising techniques are such as massive multiple-input-multiple-output (MIMO) [7, 8], millimeter-wave [9, 10], ultra-densification, offloading [11–13], and non-orthogonal multiple access (NOMA) [14]. As a result, NOMA is among the contenders for realizing the 5G wireless technology goal. Also, NOMA is a technique to serve various users through a single wireless resource [15]. Improving the performance of the NOMA system depends highly on the resource allocation schemes (i.e., user pairing (UP) schemes and power allocation (PA) schemes). Hence, numerous researchers were motivated to focus their contributions to this field. Accordingly, this paper distinguishes itself from previous research in displaying most solution schemes used to solve the UP issue, the PA issue, and the join user pairing and power allocation (UPPA) issue. Also, the objective of each scheme, how to implement their operation steps, and the comparison between them are studied. Specifically, the paper contributions can be brief as follows:

- Present a review of the multiple access techniques and a comparison between them.
- Introduce a survey about the basis of the NOMA system, NOMA features, NOMA challenges, and a comparison with the orthogonal multiple access (OMA) technique.
- Investigate the resource allocation issue of the NOMA system, along with its solutions schemes.
- Finally, this paper explores several challenges and forthcoming trends related to the NOMA system.

The rest of the paper is organized as follows: Sect. 2 presents a survey of the multiple access techniques. Section 3 investigates the fundamentals of the NOMA system. Section 4 discusses the resource allocation issue and its solution for the NOMA system. Section 5 studies the research challenges and upcoming trends. Finally, Sect. 6 concludes the paper.

2 Multiple access techniques

Several multiple access (MA) schemes are used in cellular communication radio access technologies to serve various users with limited bandwidth resources [16]. As a result, the MA scheme has a considerable impression on spectrum use, system throughput, and latency [17]. The MA scheme refers to a technique in which several users share similar radio resources to build connections with a base station (BS) in any cellular system [18]. The two types of MA techniques are orthogonal multiple access (OMA) and non-orthogonal multiple access (NOMA) [19].

An OMA approach enables multiple users to be assigned resources that are orthogonal, in time, frequency, or coding domain, to prevent multiple access interference. Previous generations of networks applied OMA schemes such as first-generation (1G) frequency division multiple access (FDMA), second-generation (2G) time division multiple access (TDMA), third-generation (3G) code division multiple access (CDMA), and fourth-generation (4G) orthogonal frequency division multiple access (OFDMA) [15], and [19–27].

However, these OMA schemes have lower spectral efficiency since users cannot share the same resource. Additionally, certain users with good channel conditions have a higher priority to be served, while others with poor channel conditions cannot guarantee good service, resulting in a considerable level of unfairness and a broad range of delays in delivering the service to part of users. As a result, existing OMA techniques are insufficient for 5G networks to sustain large mobile users' connections and IoT devices connections with varying QoS requirements [16]. Thus, in 5G and beyond networks, advanced multiple access technologies are needed to support these requirements. Among the promising candidates for 5G and beyond multiple access, in particular, NOMA has attracted much interest [14–16], and [28–30]. Table 1 presents a comparison between the MA techniques in successive generations of cellular networks.

On the other hand, the NOMA system uses power domain or code domain multiplexing to allow numerous users to share the same radio resources. At the same time, it permits excellent spectral efficiency, minimal transmission latency, and massive connectivity. Power-domain NOMA (PD-NOMA) and code-domain NOMA (CD-NOMA) are the two main types of NOMA systems [31–37]. In addition to the PD-NOMA and CD-NOMA, there are other NOMA methods such as pattern division multiple access (PDMA) [38, 39], spatial division multiple access (SDMA) [40–44], and bit division multiplexing (BDM) [45].

The CD-NOMA uses sparse or non-orthogonal spreading sequences that are user-specific for a minimal coefficient of correlation cross-correlation [46]. Multiuser shared access (MUSA) [47], sparse code multiple access (SCMA) [48], successive interference cancellation amenable multiple access (SAMA) [49], and low-density spreading (LDS) [50–56] are instances of CD-NOMA Schemes. Although the CD-NOMA can improve spectral efficiency, it is hard to apply to the existing systems because it needs a high transmission bandwidth. On the other hand, in the PD-

Table 1 A comparison between the MA techniques in successive generations of cellular networks

Features of the cellular network generations	1G	2G	3G	4G	5G
MA Techniques	FDMA	TDMA/ CDMA	CDMA	OFDMA	NOMA
Duration	1970–1980	1990–2004	2004–2010	2010 to Now	Around 2020
Data rate	2Kbps	64Kbps	2Mbps	1Gbps	More than 1Gbps
Frequency	30 kHz	1.8 GHz	1.6–2 GHz	2–8 GHz	3–30 GHz
Technologies	Analog cellular, AMPS, NMT	Digital cellular, GSM, IS-54	WCDMA, CDMA 2000, UMTS, EDGE	WiMax, LTE, LTE-A	5G-New Radio, MIMO, mm Waves
Duplex Method	FDD	FDD	FDD/TDD	FDD/TDD	FDD/TDD
Physical resource	Frequency	Time Slots	Time Slots/PN Codes	Orthogonal Frequency	Power domain/ Code domain
Services	Analog voice	Digital voice, SMS, MMS	Faster communication, higher-quality Audio/Video Data	Wearable devices, mobile multimedia, real-time information access	Wearable devices with artificial intelligence, 3D gaming, interactive multimedia, video Streaming, IoT
The network's core	PSTN	PSTN	Packet network	Internet	Internet
Hand off	Horizontal	Horizontal	Horizontal	Horizontal/ Vertical	Horizontal/Vertical

NOMA, different power levels are allocated to various users depending on their channel state, while the transmitter side uses the same time, frequency, and code resources. The PD-NOMA does not need more bandwidth to enhance spectral efficiency, and it is straightforward to implement because it does not require any modifications to current networks [57]. Figure 1 depicts a simplified classification of MA techniques including both OMA and NOMA schemes.

3 Fundamentals OF NOMA system

The basic principle of the NOMA scheme is that several users can utilize the same wireless resources, in either the code domain for CD-NOMA or the power domain for PD-NOMA, leading to non-orthogonality in user access. This paper focuses on PD-NOMA system, where different power levels are assigned to users sharing the same resources [58]. Also, the PD-NOMA promotes user fairness by providing high transmission power to the user with a lower channel gain. On the other hand, the user with better channel gain receives less transmission power. This implies that users' power coefficients are distributed among paired users inversely proportional way with their channel conditions [59]. Furthermore, one subcarrier can be allotted to multiple users in the NOMA scheme, and each user can acquire data from various subcarriers.

3.1 Superposition coding and successive interference cancellation (SIC)

Figure 2 illustrates the transmission in the downlink NOMA system, in which the NOMA scheme employs superposition coding on the side of the transmitter [60]. The superposition coding can aggregate all-users signals to superpose several users on the side of the transmitter. Thus, the superposition coding scheme employs encoding several user signals on the side of the transmitter. Since the superposition coding scheme can achieve the channel capacity, it is an effective method for improving spectral efficiency in the NOMA system without expanding the bandwidth. On the other hand, to decode multi-user signals at the receiver, the NOMA system uses multi-user detection (MUD) techniques like successive-interference-cancellation (SIC) [61]. As a result, the SIC is an excellent way for dealing with interference at the receiver, resulted from the fact that multiple users are paired on the same resources. The selection of the SIC decoding sequence depends on the users' channel state information (CSI). So, the first user's signal that SIC decodes is the strongest one while the others are treated as an intrusion. As a result, users with high channel gain (e.g., user 1) remove other users' messages by employing SIC before decoding its message. Furthermore, users with low channel gain (e.g., user 2) decode its messages directly considering other users' messages as intrusions.

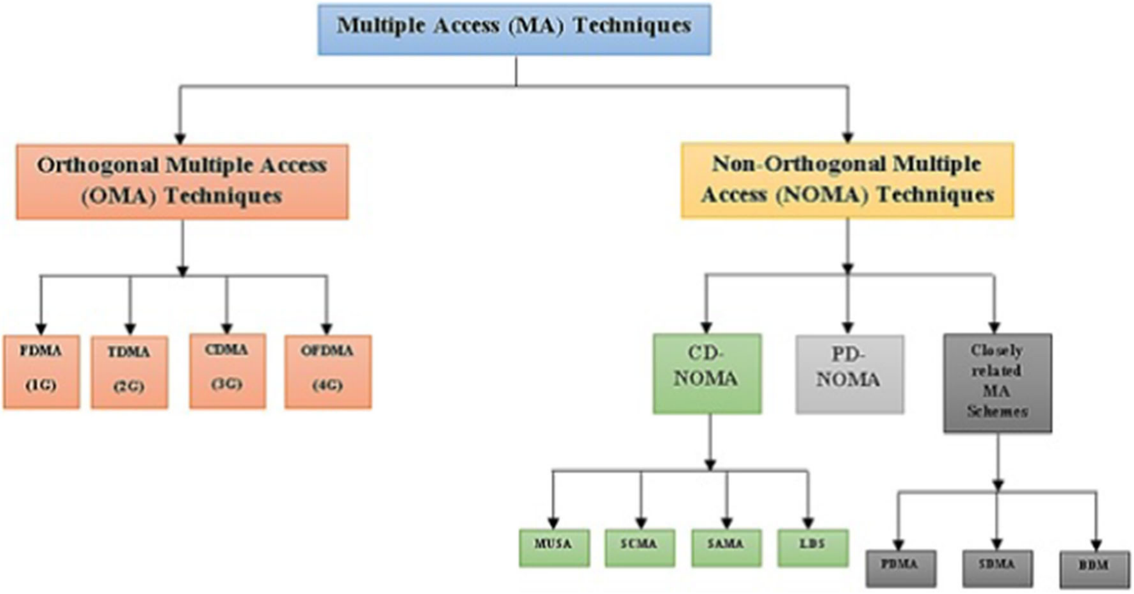
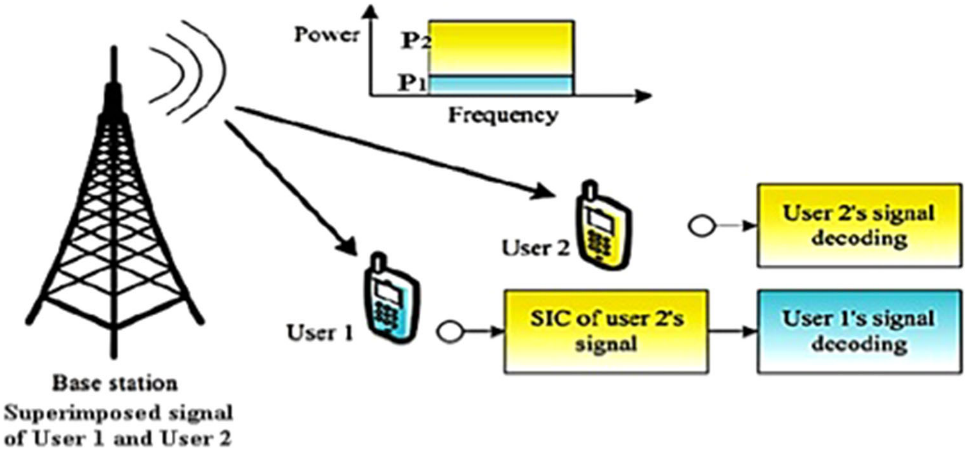


Fig. 1 A simple classification of MA techniques

Fig. 2 The transmission in the downlink NOMA system [15]



3.2 Transmission of multi-user NOMA system

Figure 3 displays a downlink multi-user NOMA system in which a BS provides data to a group of users denoted by the indices $k \in \{1, \ldots.., K\}$, where K is the total number of users. The whole available bandwidth B is equally divided between S subcarriers, each with $B_s = \frac{B}{S}$, and the set of available subcarriers with indices $s \in \{1, \ldots.., S\}$, where S is the total number of potential subcarriers. The BS is supposed to have complete knowledge about the CSI. The BS distributes a subset of subcarriers to a group of users. Also, the BS provides different levels of power to each user according to the CSI of each subcarrier. Each subcarrier is assumed to be able to assign to K_s users, where K_s is the number of multiplexed users on the subcarrier s. Consequently, the number of users is supposed to be K=K_s S [62, 63]. Following that, the signal transmitted from the BS to the K_s users on the subcarrier s is described as [17, 19], and [64–67]:

$$x_s = \sum_{k=1}^{K_s} \sqrt{P_{s,k}} \quad M_{s,k}, \tag{1}$$

where $P_{s,k}$ denotes the amount of power allotted to user k on subcarrier s. Moreover, $M_{s,k}$ refers to the message signal sent to user k on subcarrier s.

The received signal of user k on subcarrier s can be described as in [17, 19, 64, 65], and [67]:

$$\begin{aligned} y_{s,k} &= h_{s,k}x_s + Z_{s,k} \\ &= \sqrt{P_{s,k}}h_{s,k} \quad M_{s,k} + \sum_{i=1, i\neq k}^{K_s} \sqrt{P_{s,i}}h_{s,k} \quad M_{s,i} + Z_{s,k}, \end{aligned} \tag{2}$$

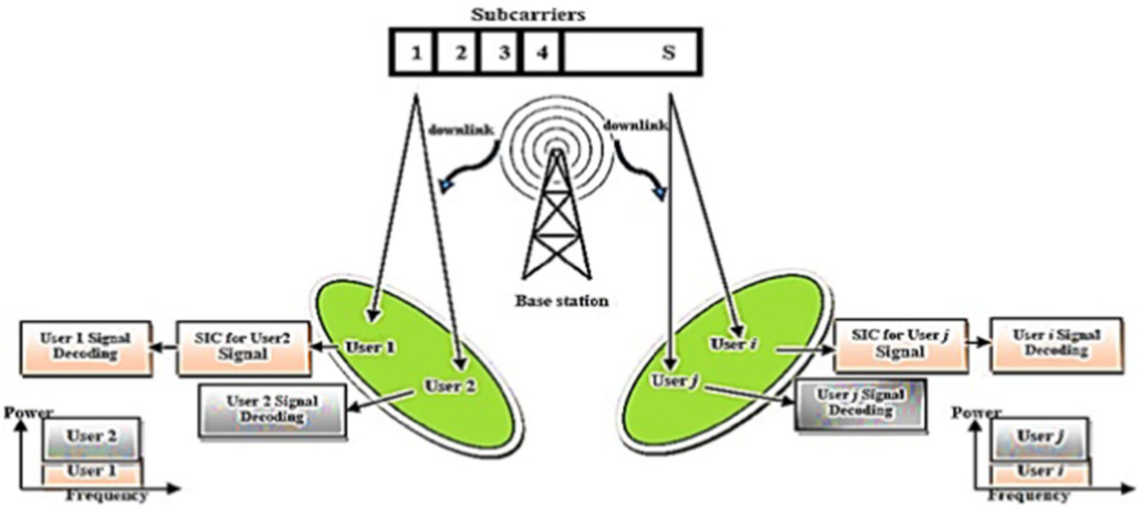


Fig. 3 A downlink Multi-user NOMA system

where $h_{s,k}$ is the complex channel gain on subcarrier s from the BS to the kth user, and $Z_{s,k}$ is the "complex additive white Gaussian noise" (AWGN) at user k with zero mean and variance $\sigma^2 = N_0 \frac{B}{S}$, where N_o is the noise-power-spectral-density. The receiver can use the SIC technique to demodulate the required signal at the receive side, where the descending order of channel gains normalized by noise plays a vital part in implementing the SIC operation. Suppose the users on the same subcarrier s have their channel gain normalized by noise arranged in descending order as follows:$\frac{|h_{s,1}|^2}{\sigma^2} \geq \ldots \geq \frac{|h_{s,k}|^2}{\sigma^2} \geq \ldots \geq \frac{|h_{s,K_s}|^2}{\sigma^2}$. Without implementing the SIC approach, the reception of user K_s (i.e., the user with the worst channel gain on subcarrier s) can demodulate its signal message M_{s,K_s} immediately and regards the signals of other users as interfering. Instead, the receiver of user 1 (i.e., the user with the best channel gain on the same subcarrier s) demodulates other users' signals first, then removes them from the superimposed received signal. User 1 can then demodulate its signal $M_{s,1}$ without any intrusions from other users' signals.

To ensure fairness and make the SIC procedure simple for the paired users in NOMA, the BS will provide the low-channel-gain user greater power, i.e., $P_{s,1} \leq \ldots \leq P_{s,k} \leq \ldots \leq P_{s,K_s}$.As a result, after the SIC procedure, the received signal to the interference plus noise ratio (SINR) of the user k on subcarrier s is expressed as [59, 62], and [68, 69]:

$$SINR_{s,k} = \frac{P_{s,k}|h_{s,k}|^2}{\sum_{i=1,i\neq k}^{k-1} P_{s,i}|h_{s,k}|^2 + \sigma^2{}_s}, \tag{3}$$

Then, the attainable data rates of the kth user on the subcarrier s can be described as [17, 19], and [64, 65]:

$$\begin{aligned} R_{s,k} &= B_s \log_2(1 + SINR_{s,k}) \\ &= B_s \log_2\left(1 + \frac{P_{s,k}|h_{s,k}|^2}{\sum_{i=1,i\neq k}^{k-1} P_{s,i}|h_{s,k}|^2 + \sigma^2{}_s}\right), \end{aligned} \tag{4}$$

Then, the total system sum-rate is given by:

$$R_T = \sum_{s=1}^{S} R_s, \tag{5}$$

where, $R_s = \sum_{k=1}^{K_s} R_{s,k}$ is the total sum-rate for subcarrier s.

3.3 Comparison with OMA

The performance evaluation of the NOMA system was accomplished in recent research mostly in relation to the OMA system [15, 17, 19, 63–65], and [70–72] (i.e., when a resource orthogonally distributes in bandwidth and power among multiplexed users). To gain a comparative knowledge of the NOMA and OMA systems' performance, Fig. 4 displays the spectrum usage of them in the downlink, where the 1 Hz transmission bandwidth divides between the two users. For the NOMA system, the BS will assign higher powers to the weak user (user 2) and less powers to the strong user (user 1) according to the NOMA standard, resulting in $P_1 < P_2$ [62], and [66]. Subsequently, the data rates of users 1and 2 that achieve in the NOMA system are calculated, respectively, as follows [14, 15, 17, 21], and [64, 65]:

$$R_1{}^{NOMA} = \log_2\left(1 + \frac{P_1|h_1|^2}{\sigma^2}\right), R_2{}^{NOMA} = \log_2(1 + \frac{P_2|h_2|^2}{P_1|h_2|^2 + \sigma^2}), \tag{6}$$

Then, the total achievable sum capacity of the NOMA system is given by:

$$R_T{}^{NOMA} = R_1{}^{NOMA} + R_2{}^{NOMA}, \tag{7}$$

For OMA as orthogonal user pairing, the bandwidth of β $(0 \leq \beta \leq 1)$ Hz is allotted to user 1 and the residual bandwidth $(1 - \beta)$ Hz, is allotted to user 2. Then, the achievable data rates in the OMA system of user 1, and user 2, respectively, can be expressed as [15, 17, 63–65], and [70–72]:

$$R_1{}^{OMA} = \beta\log_2(1 + \frac{P_1|h_1|^2}{\beta\sigma^2}), R_2{}^{OMA} = (1 - \beta)\log_2\left(1 + \frac{P_2|h_2|^2}{(1 - \beta)\sigma^2}\right), \tag{8}$$

After that, the total achievable sum capacity of the OMA system is represented as:

$$R_T{}^{OMA} = R_1{}^{OMA} + R_2{}^{OMA} \tag{9}$$

The previous capacity analysis confirmed that the NOMA system provides significant performance gains over the OMA system. Compared with OMA, the key features of NOMA are reviewed as follows [23, 25, 31, 35], and [72–75]:

(1) **Increased Spectral Efficiency (SE):** NOMA is very spectrum-efficient since it can support numerous users with the same time–frequency resource. Thus, it can raise system throughput.

(2) **Improved user fairness:** The NOMA system permits a more versatile organization of radio resources and an effective means to promote user fairness through optimal resource distribution by loosening the orthogonal requirement of the OMA scheme.

(3) **Massive connectivity:** The NOMA system's non-orthogonal resource distribution means that the number of users or devices supplied is not restricted by the number of resources available. By using the less non-orthogonal distribution of resources, the NOMA scheme can service a higher number of users than the OMA method.

(4) **Compatibility:** Because the NOMA approach takes advantage of a novel dimension, the power-domain, it can be considered an "add-on" method to any current OMA technique. NOMA can be associated with current MA techniques due to the fully matured situation of superposition coding and SIC approach in theory and practice.

(5) **Low signaling and transmission latency:** The OMA technique depends on the access-grant required in the uplink, which increases latency and signaling cost that is not desirable on the 5G connectivity. On the opposite side, the NOMA system allows a grant-free uplink transmission, which diminishes the transmission delay and signaling overhead significantly. Further, serving multiple users in the NOMA scheme also reduces latency.

Furthermore, the disadvantages of the NOMA scheme can be summarized as follows [15]:

(1) The CSI feedback overhead is enlarged because the BS must recognize the ideal CSI to achieve the SIC scheme's optimal decoding order.

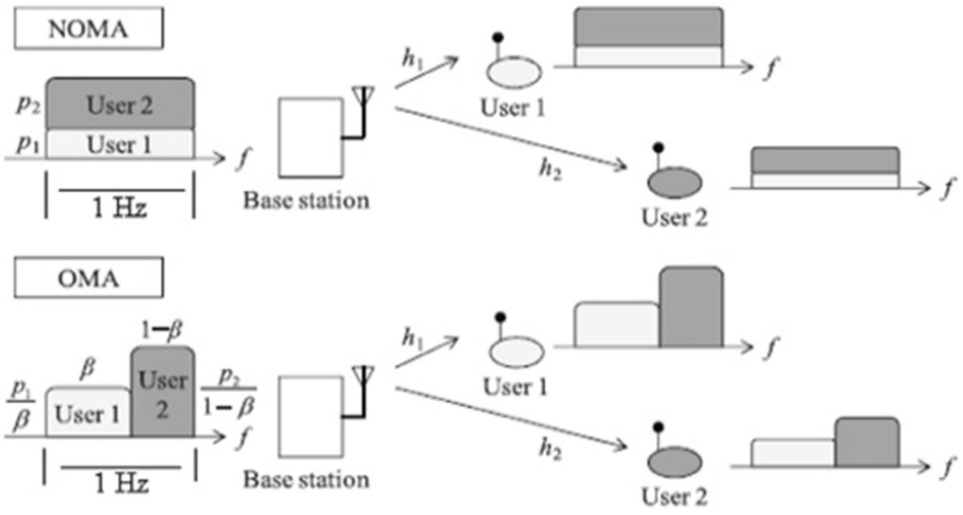


Fig. 4 Spectrum usage by the NOMA and OMA downlink systems [65]

(2) The receiver side has a higher computational complexity, particularly for multicarrier and multiuser systems because of the SIC process.
(3) The system signaling overhead is raised because the strong user should know the power distribution of the weaker user to execute SIC.
(4) Additional inter-cell interferences are added to the entire system because of allocating more power to the weak users.

Table 2 displays a comparison between the OMA scheme and the NOMA scheme.

4 Resource allocation issue for NOMA system

The Resource Allocation represented in power allocation (PA) and subcarrier-user assignment (SUA) or user pairing (UP) is essential to optimize the performance of NOMA Systems. Up means how each one of the subcarriers selects its multiplexed users. On the other hand, PA means how the BS divides its overall power budget across the subcarriers and how the power per subcarrier distributes to the users who share the same subcarrier. Hence, the purpose of the UP and PA schemes is to achieve any of a variety of performance measures, such as:

(1) Increase the total system capacity, subsequently improve SE and EE.
(2) Reduce the outage probability.
(3) Increase the data rate of weak users.
(4) Enhance the SIC performance.
(5) Improve the fairness among users.
(6) Minimize the power consumption.

4.1 User pairing (UP)

In the UP process, the users are paired depending on the difference in channel gains. The big difference in channel gain between paired users makes the SIC operation easier and increases the overall system capacity. Thus, we will discuss various UP schemes used to solve UP issue in PD-NOMA, as well as their goals. Then, Table 3 summarizes different schemes for solving the UP issues in the NOMA system.

4.1.1 UP schemes for raising the total system capacity:

In [76], two impact UP schemes, named NOMA with fixed power allocation (F-NOMA) and cognitive-radio-inspired NOMA (CR-NOMA), are investigated to recognize the users' channel gains in the pairing process and improve the entire system sum rate. The F-NOMA pairs the user of the best channel condition with the user of the poorer channel condition. The CR-NOMA pairs the user of the best channel condition with the user of the second-best channel condition. The F-NOMA furnishes a higher sum rate than OMA. Conversely, the CR-NOMA guarantees the QoS for users with lower channel conditions. But F-NOMA and CR-NOMA reduce the system spectral efficiency and make SIC operation more complex. Because the subcarrier-users allocation doesn't consider which subcarrier will start the allocation procedures and may select users with very close channel gain value.

A channel-state-sorting-pairing algorithm (CSS-PA) and user difference selecting access (UDSA) algorithm are suggested in [77] as UP scheme and new user access scheme, respectively. By considering the users' channel conditions, the CSS-PA algorithm and UDSA algorithm put the prospect users in ascending order at first. Then, pair the sorted users by the binary dislocation principle (BDP) in which BDP pairs the first user with the K/2th user, the second user with the (K/2 + 1) user, and preserves the pairing like this until no prospect user is departed. Considering users' channel conditions, these two algorithms improve system capacity and SIC reception.

The two UP methods, named uniform channel gain difference (UCGD) pairing and hybrid UP algorithms, are presented in [78]. These two UP approaches aim to raise the overall channel gain disparities of the in-pair users for all paired users by eliminating cell-center users from pairing. In the UCGD scheme, the high gain users joined with cell-center users in place of cell-edge users, and the cell-center users joined with cell-center or cell-edge users. The hybrid UP scheme keeps on F-NOMA for the highest end-users with a high disparity in channel gain. When the difference in channel gain between users becomes small, the hybrid UP scheme moves to the UCGD pairing. Consequently, practically all users' capacity rises, especially when studying defective SIC, and the issue of UP in the cell center is alleviated.

In [79], a virtual-UP technique is employed to optimize the spectrum of un-paired users in NOMA systems and boost the NOMA system's capacity, in which a close user can be paired with several far users. In the virtual-UP technique, a close user and a far user use half of the frequency band, and a close user and the other far user use the other half of the frequency band. An SUA algorithm for the NOMA system is introduced in [80] to increase SE by raising the total system sum rate and maintaining the substantial channel gain disparities across the pairing users per subcarrier to improve the SIC process. This SUA algorithm separates the subcarriers into two groups consistent with the standard deviation of each subcarrier's channel gain. The group with the lowest standard deviation

Table 2 A comparison between the OMA scheme and the NOMA scheme

	OMA	NOMA
Advantages	• Receiver complexity is low	• Increased SE • Improved user fairness • Massive connectivity • More compatibility • Small signaling and transmission latency
Disadvantages	• Reduced SE • The fairness between users is bad • Restricted number of users • High transmission latency	• Increase the CSI feedback overhead • Increase the complexity of the receiver • Increase the system signaling overhead • Increase the inter-cell interferences

values is then given precedence during SUA to ensure a large differential in channel gain among the multiplexed users per subcarrier. In addition, this SUA algorithm boosts the SE by matching the strong user with the second minimum channel-gain user instead of the minimal channel-gain user.

The matching theory is employed in [59, 62, 68], and [81–83] to resolve the UP issue in the NOMA system to optimize the total sum rate with adequate complications. The main idea of the matching procedure is that users and subcarriers consider as two sets of players (proposers and selectors) who must combine to obtain the maximum sum rate. Each user and subcarrier create their own preferences lists which must match their channel status. Then, the users (proposers) send a request to their preferred subcarrier. Subsequently, depending on the subcarrier's preference list, this chosen subcarrier (selector) has the authority to approve or deny the user's request.

4.1.2 UP schemes for improving fairness

In [84], a divide and next-largest-difference-based UP algorithm (D-NLUPA) is presented to promote fairness between NOMA clusters and provide a minimal sum-rate gain for each cluster. The D-NLUPA implements a divide step by defining a shorter range and raising the supported minimum distance value. The case of relatively close gain clusters may be averted. Then, each cluster receives a minimal gain as planned of this "divide" step. The value of this minimum gain is determined by how the users are randomized during the "divide" stage.

A weighted proportional fair (PF) scheduling mechanism is recommended in [85] for the NOMA scheme. This suggested scheduler incorporates fair weights into the standard PF scheduling criteria. The PF scheduler goals to maximize data rates while also assuring fairness among users within each scheduling slot, hence improving each user's QoS. In addition, the suggested scheduler allows for different degrees of QoS to be delivered, which can be highly valuable for specific applications.

In [86], the generic optimization model of dynamic UP and beamforming scheme is used to attain better rate fairness among users. This dynamic UP is executed by adding binary variables, in which a tough category of mixed-integer nonconvex optimization issues is created. Then, the binary constraints are relaxed, and a low-complexity iterative algorithm based on the inner approximation (IA) framework is suggested for its answer. The comprehensive exploration of all conceivable UP situations yields the best performance for the supposed issue, but with excessive complexity.

The worst-case user first subcarrier allocation (WCUFSA) algorithm is advised in [87] to optimize fairness among users. The WCUFSA algorithm achieves excellent results in distributing and allocating better subcarriers to users with sufficient complexity. Also, it prevents the allocation of a user with poor channel conditions in the final stage. The WCUFSA algorithm depends on detecting the subcarrier with the minimum channel quality for each user. Then, The WCUFSA algorithm sorts the users in ascending order consistent with the subcarrier with minimum channel quality and selects the subcarrier with the highest channel gain for each sorted user.

The fixed-rate splitting (FRS) and the cognitive rate splitting (CRS) techniques are implemented in [88] to actualize RS for uplink NOMA to increase user fairness and outage performance in delay-restricted communications. For the FRS and CRS schemes, the transmit power distributes to the near and the far users in either a fixed or cognitive method depending on the divided data streams. In addition, by using FRS and CRS approaches, closed-form equations for the outage probabilities of both users have been developed.

The worst subcarrier first-based SUA algorithm (WSF-SUAA) and spectral efficiency maximization-based SUA algorithm (SEM-SUAA) are implemented in [89] to

Table 3 Summary of different schemes for solving the UP issues in the NOMA system

Reference	Algorithm	Its Improvement/Achievement	Limitations/Weakness
[76]	NOMA with fixed power allocation NOMA (F-NOMA)	Recognize the users' channel gains in the UP process Provide larger NOMA throughput than OMA throughput	Give low system spectral efficiency Make the SIC operation more complex
[76]	The cognitive-radio-inspired NOMA (CR-NOMA) algorithm	Recognize the users' channel gains in the UP process Guarantee the QoS for users with the lower channel gains	Give low system spectral efficiency Make the SIC operation more complex
[77]	The channel state sorting pairing algorithm (CSS-PA) and User Difference Selecting Access (UDSA) Algorithm	Improve the system capacity Enhance the NOMA system's functionality with the SIC reception by taking into consideration the users' channel characteristics	Doesn't consider multi-user pairing on the same resources
[78]	The uniform channel gain difference (UCGD) pairing algorithm and the hybrid up algorithm	Raise the overall channel gain disparities of in-pair users for all paired users Increase Capacity for almost all the users Mitigate the cell-center UP problem	Doesn't consider multi-user pairing on the same resources Doesn't consider the enhancement of SIC operation performance
[79]	The virtual-UP algorithm	Adapt the un-paired user's spectrum in NOMA systems efficiently Increase the capacity of the NOMA system	Doesn't consider the enhancement of SIC operation performance
[80]	The subcarrier-user allocation algorithm	Increase SE by raising the total system sum rate Enhance the SIC performance	Doesn't consider multi-user pairing on the same resources
[59, 62, 68], and [81–83]	The UP using Matching Theory	Maximize the total sum-rate with adequate complexities	The SIC operation may be difficult
[84]	The divide and next-largest-difference-based UP algorithm (D-NLUPA)	Achieve fairness between the NOMA clusters Ensure a minimal sum-rate gain for each cluster	Doesn't consider multi-user pairing on the same resources
[85]	The weighted proportional fair (PF) scheduling mechanism	Provide a substantial increase in total user throughput Obtain a high level of fairness inside each scheduling slot and advance each user's QoS	Doesn't consider the enhancement of SIC operation performance
[86]	The dynamic UP and beamforming design	Achieve higher rate fairness among users	Increase complexity
[87]	The Worst-Case User First Subcarrier Allocation (WCUFSA) Algorithm	Optimize fairness among users Provide great realization in distributing and allocating better subcarriers to users	Doesn't consider multi-user pairing on the same resources
[88]	The FRS and the CRS Techniques	Enhance the outage performance and the user fairness	Doesn't consider multi-user pairing on the same resources
[89]	The WSF-SUAA and SEM-SUAA	Improve SE and fairness between users	Doesn't consider multi-user pairing on the same resources

improve SE and fairness between users. To resist picking a user with the greatest worst channel gain for any subcarrier, the WSF-SUAA arranges subcarriers in increasing form along with the user with the worst channel gain that is decided for each subcarrier before the SUA procedures. On the other hand, the SEM-SUAA depends on thorough research. Both algorithms base their allocation procedure on increasing the data rate of each user by keeping the channel gain of the multiplexed users per subcarrier as large as possible.

4.2 Power allocation (PA)

The PA impacts not only one user's throughput but also the throughput of other users. Ineffective PA schemes can lead to severe intrusion, user unfairness in rate allocation among paired users, system outages owing to SIC breakdown, and energy inefficiency problems, all of which affect NOMA efficiency. Consequently, different PA schemes are explored below to show how the PA issue in the NOMA system is solved. Next, Table 4 summarizes the difference between various PA schemes.

4.2.1 Low complexity PA schemes-based closed formula

In [70], a low complexity PA scheme named the Fixed Power Allocation (FPA) algorithm is investigated. The FPA algorithm distributes the power per subcarrier s (P_s) between its two paired users i, j according to a fixed parameter δ. Thus, the allocated power to the strong user i equals to $P_{s,i} = \delta P_s$. Conversely, the allocated power to the weak user j equals to $P_{s,j} = (1-\delta)P_s$, in which δ ($0 < \delta < 0.5$) is a constant parameter over all subcarriers. Thus, the FPA algorithm is considered an ineffective method due to the failure to consider the users' channel conditions in defining the power levels.

A suboptimal Fractional Transmit Power Allocation (FTPA) algorithm is adopted in [70, 71]. According to the channel gains, the power per subcarrier s (P_s) is distributed between its two paired users i, j in the FTPA algorithm. Consequently, the power assigned to the strong user i equals to $P_{s,i} = \rho_s P_s$. Then, the power allocated to the weak user j equals to $P_{s,j} = (1-\rho_s)P_s$. The ρ_s ($0 < \rho_s < 0.5$) is a dynamic parameter and is given by:

$$\rho_s = \frac{\left(|h_{s,i}|^2\right)^{-\mu}}{\left(|h_{s,i}|^2\right)^{-\mu} + \left(|h_{s,j}|^2\right)^{-\mu}} \tag{10}$$

where $\mu (0 \leq \mu \leq 1)$ is the FTPA decay power-distribution factor and $\mu = 0$ indicates that the power distribution is equal. The $h_{s,i}$ and $h_{s,j}$ represent the complex channel coefficient from the BS on subcarrier s to the user i and user j, respectively. Users having lower channel gain can increase their power by increasing μ. μ is held constant across all subcarriers and assessed using computer simulations. Although the FTPA algorithm depends on the users' channel conditions, it requires preliminary computer simulation to select a system parameter to get the greatest execution.

Two PA schemes for the NOMA system are proposed in [90] to realize high performance compared to the OMA system. The first scheme relies on the channel status of NOMA users, in which the BS combines one user with better channel conditions with another user with bad channel conditions. After that, each user group allocates to a subcarrier. The ith user's PA coefficient is represented by:

$$P_i = \frac{P_s}{|h_i|^2 \sum_{k=1}^{2} |h_k|^2}, i \neq k \tag{11}$$

The second scheme relies on a pre-defined QoS per NOMA user in which two sorts of users assume: high priority users and low priority users. The BS then combines a high-priority user with a low-priority user across the same subcarrier and assigns the power needed to the high-priority user. Then, the remainder of the power distributes to the user with the lowest priority. Consequently, the PA coefficients of the high priority user and low priority user are expressed, respectively, as:

$$P_i = \frac{SINR_h\left(|h_h|^2 + \frac{\sigma^2}{P_s}\right)}{|h_h|^2(SINR_h + 1)} P_s, P_l = P_s - P_h \tag{12}$$

where h_h represents the complex channel coefficient of the high priority user, and $SINR_h$ denotes the received signal to the interference plus noise ratio (SINR) of the high priority user.

A PA technique for capacity and fairness maximization, named (CFM-PA), is advised for the NOMA system in [91]. The PA coefficient (i.e., α) of CFM-PA is designed as an exponentially decaying function of the proportion among the multiplexed users' channel gain (i.e., γ) to maximize the capacity and the fairness. Then, to achieve these goals, the suggested relationship between α and γ is written as follows:

$$\alpha = \alpha_{max} e^{-3\gamma}, \alpha_{max} = 0.5\left(1 - \frac{\theta}{P_s|h_{s,1}|^2}\right) \tag{13}$$

Also, the maximum PA coefficient value (i.e., α_{max}) is modified to ensure the SIC restriction, which is:

$$[(1-\alpha)P_s - \alpha P_s]|h_{s,1}|^2 \geq \theta \tag{14}$$

where θ denotes the desired minimum gap between the received powers of multiplexed users.

4.2.2 PA schemes depends on exhaustive search

To improve the efficiency of the NOMA system, we need to reduce the complexity and reach the optimal solution. But, achieving the optimal solution requires a more exhaustive search. So, we will display some algorithms that achieve the optimal solution for the PA issues, but increase the complexity of the NOMA scheme.

The Full Search Power Allocation (FSPA) algorithm is presented in [70] to guarantee the desired execution of the NOMA scheme. In the FSPA algorithm, the power per

Table 4 The difference between various PA schemes

Ref	Objectives/ Contributions	Link type	Solution scheme	Characteristics/Achievement	Limitations/ Weakness
[70]	Divide the power per subcarrier among the two users who are paired with it	Downlink NOMA	FPA	Has the lowest complexity	It is considered an ineffective method
[70] and [71]	Divide the power per subcarrier on its two paired users consistent with its channel gains	Downlink NOMA	FTPA	Achieve good performance with less complexity	It requires preliminary computer simulation to select a system parameter to get the greatest execution
[90]	Realize greater performance compared to that of OMA	Downlink NOMA	Two PA schemes with closed formula	The first scheme depends on the channel state information The second scheme depends on pre-defined QoS per NOMA user	Distribute the power to two paired users, not multi-paired users
[91]	Maximize the capacity and fairness, and guarantee the SIC constraints	Downlink NOMA	CFM-PA	Outperforms the OMA system	Distribute the power to two paired users, not multi-paired users
[70]	Achieve an optimal solution of PA between paired users per subcarrier	Downlink NOMA	FSPA	Achieve the best performance with exhaustive search	High computational complexity
[92]	Reduce the computational complexity of the FSPA algorithm	Downlink NOMA	Novel PA method	Is a fair and impartial balance between computational complexity and total throughput performance	Still needs an exhaustive search
[93]	Maximize the NOMA system's sum rate	Downlink NOMA	GAPA algorithm	Reach a performance near to FSPA with lower complexity	Still needs an exhaustive search
[94]	Maximize the system capacity	Downlink NOMA	Water-filling-based PA Scheme joined with the PF scheduler	Enhance both system capacity and user fairness	Increase the PF computational load by using the number of additions and multiplications
[95]	Maximize the total sum rate	Downlink SISO NOMA	Optimization Scheme based on KKT Conditions	Achieve near-capacity performance	Need much lower computational complexity
[96]	Maximize the total sum rate	Downlink NOMA	The simple alternate optimization (AO) Algorithm	Outperform the conventional OMA for both the situations with analytical and accurate CSIT	Need several arithmetic operations in each iteration which increase complexity
[97]	Maximize the ergodic sum rate	Downlink NOMA	Threshold-based PA optimization scheme	Outperform the bisection search technique related to the BER of users with similar capacity results	Increase the complexity because of high searching
[98]	Maximize the total sum rate	Downlink NOMA	PA Method based on GA	Outperform OMA systems related to the achievable sum rate	Take a long time to reach the optimal solution
[99]	Maximize the total sum rate	Downlink SISO NOMA	Two optimization PA methods, one utilizes the PSO algorithm and the other uniformly apportions the power over all sub-bands	Achieve the system throughput Preserve a high level of fairness between users	Take a long time to reach the optimal solution
[100]	Maximize the WSR	Downlink NOMA	Optimization PA method with and without QoS constraints	Can be omitted without sacrificing any optimality if the QoS criteria are not particularly small, which is frequently the case in practice,	Take a long time to reach the optimal solution
[101]	Maximize the WSR	Downlink MC-NOMA	Optimization with the first-order approximation and then an iterative PA algorithm	Achieve a superior WSR performance to OFDMA scheme and average PA scheme	Take number of iterations to reach the optimal solution

Table 4 (continued)

Ref	Objectives/ Contributions	Link type	Solution scheme	Characteristics/Achievement	Limitations/ Weakness
[102]	Maximize EE	Downlink MU-NOMA	Closed form based on the KKT conditions, and Iterative method based on Dinkel Bach algorithm and DC-Programming	Has better performance compared to conventional OMA	Take number of iterations to reach the optimal solution
[103]	Maximize EE and SE	Downlink MU-NOMA	The dual decomposition technique	Not only outperforms the conventional benchmark NOMA scheme but also beats its equivalent OMA schemes related to both SE and EE	The complexity is slightly high
[104]	Maximize EE	Downlink NOMA	Optimization with low complexity PA scheme	Has much lower complexity and a fast optimal solution	Doesn't consider the PA to multiple users per subcarrier
[106]	Maximize WEE	Uplink MC-NOMA	Dinkel- Bach algorithm, and Lagrange dual decomposition Approach	Provide the best power statements for a single cell MC-NOMA system in the uplink mode	The complexity is slightly high
[107]	Maximize WEE	Downlink D2D NOMA	A successive convex approximation-based technique	Achieve optimal power distribution and correlate all SNR values to the optimal levels	The complexity is slightly high
[108]	Maximize WEE	Downlink and uplink MU-NOMA	Dinkel-Bach-like as well as ellipsoid method, and the epigraph shape followed by SCA	Assign varied priorities to users, and ensure that users are treated fairly by selecting appropriate weights	The complexity is slightly high
[109]	Maximize WEE	Downlink NOMA	The WEE-PA algorithm with applying the SQP technique	Maximize the total WEE and increase the fairness between users, the data rate per weak user, the minimum user rate, and the outage probability	The complexity is slightly high

subcarrier s divides among its two paired users i, j throughout an exhaustive search. Thus, the FSPA algorithm generates all probable sets of power levels to accomplish an optimum solution with high computational complexity.

In [92], a novel PA method is considered to make the computation simpler than the FSPA algorithm. Also, the total throughput and the Geometric Mean User Throughput (GMUT) performance failure is not higher than 1.5% associated with the FSPA method. A genetic algorithm-based PA (GAPA) algorithm is employed in [93] to optimize the total rate of the NOMA system and attain a realization nearby the FSPA algorithm with lesser complexity. Unlike the FSPA method, the GAPA uses heuristics to find appropriate solutions, which not only increases the efficiency but also decreases the complexity.

4.2.3 PA optimization schemes for maximizing sum-rate and weighted sum-rate (WSR)

A low-complexity water-filling-based PA technique joined with the proportional fairness (PF) scheduler is recommended and employed in the downlink NOMA scheme in [94]. The suggested hybrid PA and scheduling strategy attempt to maximize system capacity by distributing transmit power amongst sub-bands in a quasi-optimal manner. Also, the hybrid PA and scheduling strategy maintain a high level of user fairness.

The two optimal PA schemes with closed-form solutions are suggested in [95] by employing the Karush–Kuhn–Tucker (KKT) conditions for the downlink single-input single-output (SISO) NOMA system. The optimization problem of the two optimal PA schemes is formulated under a total power constraint and the minimum rate requirements of both users instead of the minimum rate requirement of the weak user. The two optimal PA schemes increase the NOMA system's total sum rate under the total power limitation and the QoS condition.

In [96], the optimal PA approach is investigated to maximize the NOMA system's sum rate with α-fairness. The α-fairness can only employ a unique scalar to accomplish various user fairness levels. In addition, statistical and ideal channel state information at the transmitter (CSIT) views are considered. For statistical CSIT, fixed target data rates are pre-set for all users. Accordingly, the outage probability of each user is initially analyzed, and then the PA optimization framework is formulated to maximize total throughput with α-fairness. For perfect CSIT, the optimization problem is transformed into an equivalent issue by forming a sequence of parameters representing the sum PA to a set of users. Then, there is only one solution to meet KKT conditions. Furthermore, alternate optimization (AO) algorithm is suggested to generate optimal results by solving KKT conditions.

A novel threshold-based PA approach is investigated in [97] to maximize the NOMA system ergodic sum rate while avoiding interference problems between paired users. The threshold-based PA scheme follows the bisection search-based PA until the power difference threshold achieves. Next, the powers of both users are set to their last value over the rest of the higher SNR values. Moreover, an efficient PA method depending on the genetic algorithm (GA) is considered in [98] to tackle the non-linear optimization issue for maximizing the feasible sum-rate in downlink NOMA systems under a total power restriction and QoS restriction.

Two methods for PA in the downlink SISO NOMA system are considered in [99] to maximize overall throughput while maintaining a high level of user fairness The first method divides the maximum transmission power fairly across all bands, whereas the second method distributes power to each band intending to maximize total system throughput using the Particle Swarm Optimization (PSO) algorithm.

Different optimization schemes for maximizing the WSR are considered by adopting the user weights or QoS constraints, which user priority or fairness take into account. Thus, in [100], the WSR maximization in the NOMA scheme with power order and QoS restrictions are considered. Also, an analytical formula for the optimum PA is derived. An iterative PA algorithm for the multi-carrier-NOMA (MC-NOMA) system is investigated in [101] to determine the globally optimal solution for maximizing the WSR while considering user priority.

4.2.4 PA optimization schemes for maximizing energy efficiency (EE) and weighted energy efficiency (WEE)

Because of the significant rise of data traffic and wireless terminals, energy-efficient architecture for the future evolution of wireless systems is critical. Furthermore, the weighted energy efficiency (WEE) is described as the proportion of the WSR to total power consumption. Also, it has been used in numerous studies using user weights to determine user fairness and priorities. To this end, the study of PA schemes proposing to advance the EE and WEE has become an essential investigation topic in the NOMA system and studies in various research.

Thus, in [102], an optimum user PA solution using KKT conditions is investigated to maximize EE in the NOMA system with imperfect CSIT and user QoS constraints. Also, the difference between two concave functions (DC) programming and the Dinkelbach structure is employed to obtain a close-to-optimal total power value for the multiuser NOMA scheme. A unique multi-objective optimization-based strategy for properly assigning resources in downlink multi-user NOMA (MU-NOMA) schemes is investigated in [103]. This method intends to boost SE and EE while sustaining users' QoS necessities, transmit power budget, and SIC restrictions. In addition, the SIC procedure validates by realizing the restriction of the minimal gap between users who transfer powers to its shared framework. In [104], the PA problem is optimized by proposing a low complexity PA approach for each user to improve the EE for downlink NOMA systems. In this proposed PA approach, the PA fraction is proportionate to the squared space for each user.

Moreover, in [82] and [105], the optimal PA techniques for several NOMA schemes, such as two-user NOMA, MU-NOMA, and MC-NOMA, are explored. Also, these optimal PA techniques take into account various performance factors, including maximin fairness, sum rate, and energy efficiency, as well as user weights and QoS requirements. Furthermore, these optimal NOMA PA techniques give an analytical expression in most situations; alternatively, they can be determined numerically using convex optimization.

Furthermore, the system WEE maximization in the uplink MC-NOMA system investigates in [106] for obtaining the optimal energy-efficient PA expression by applying the Dinkel-Bach algorithm and Lagrange dual decomposition method. The WEE maximization of Device-to-Device (D2D) groups using facilities that enable the NOMA system is studied in [107]. In addition, a sequential convex approximation-based technique is used to obtain optimum PA. Furthermore, maximizing WEE in the uplink and downlink MU-NOMA system is studied in [108]. The optimal global solution of user PA is obtained by applying the Dinkel Bach-like algorithm. Then, a sub-gradient and cutting plane-based algorithm such as ellipsoid is considered to update the dual variables. Because the optimum solution limits the user weights, a low complexity suboptimum strategy that does not take any situation on the users' weight is involved. Therefore, the epigraph form followed by the successive convex approximation (SCA) is applied to deal with that problem.

The WEE-PA approach, which maximizes the total WEE and increases the fairness between users, the data rate per weak user, the minimum user rate, and the outage probability of the downlink NOMA system, is proposed in [109]. The optimization problem of the proposed WEE-PA approach is divided into two sub-problems and solved in two iterative matched steps to decrease the complexity caused by the increase in the number of variables. Since the optimization problem is non-convex, the sequential quadratic programming (SQP) technique is involved to solve the problem and acquire the related optimal solution.

4.3 Joint user pairing and power allocation (UPPA)

Joint optimization is frequently used to solve the problem of joint UPPA in the NOMA system. Table 5 summarizes and reviews the optimization approaches utilized to tackle the joint UPPA problem in the NOMA scheme. In [110], the UP and PA issue in the 2-user NOMA system is studied with the proportional fairness (PF) objective. The PF is assumed to be a measure of UP and PA to ensure the balance between transmission efficiency and user fairness. Then, the prerequisites for UP are obtained and employed to evade unnecessary comparisons to candidate user pairs. Next, the closed-form optimal solution organizes with the PF goal to utilize the UPPA approach design. Moreover, in [111], the sort-based UP and PA are considered to reduce interference and maximize the system capacity in the downlink MU-NOMA system. So, at first, the users are joined to reach the high difference of channel gain among users in each cluster using the two sort-based UP approaches. Then, the optimal PA is suggested to maximize the system capacity. Also, the error probability and SE are assumed under different UP strategies involved with the SIC approach.

An optimal PA solution is derived in [112] using KKT conditions to maximize the WSR constraint to maximum power. Also, a greedy user selection algorithm is applied to schedule the best set of paired users satisfying the sum PF condition. Furthermore, the joint optimization of UPPA in the NOMA system is studied in [113] to advance the PF metric conditional on transmit power constraints. Therefore, a pre-defined multi-user pairing benchmark is presented to ban a large portion of inappropriate user groups that are not suitable for PD-multiplexing. Then, an optimal PA scheme that depends on the PF scheduling metric is suggested for a particular user set. Accordingly, the uplink-downlink duality that employs the KKT conditions is utilized to convert the original non-convex multi-user PA problem to a convex problem.

The theoretical insights and algorithmic approaches for mutually optimizing channel allocation and PA in the NOMA system are studied in [114] to enhance the system performance related to sum rate and fairness over the OMA scheme. Thus, polynomial-time methods for global optimality are offered for tractable problems. Also, the NP-hardness and suggestion of an algorithmic framework combining Lagrangian duality and dynamic programming (LDDP) are introduced to create relatively close-solutions for the intractable problem. Moreover, the proportional fair scheduling (PFS) for the downlink single-carrier NOMA system is recognized in [115] by developing a low-complexity approach for combined PA and user set selection (USS). Consequently, an arbitrary number of users are paired, and a closed-form solution of the optimal PA with the PF target is derived. The performance of the low-complexity approach for combined PA and USS acts as the upper bound for various PFS schemes in practical NOMA techniques. In [116], the power-efficient allocation of resources in the MC-NOMA system is studied to reduce overall transmit power. Also, for collaborative designs of the PA, rate allocation, user scheduling, and SIC scheme, the imperfection of CSIT and user QoS requirements are considered.

A Joint UPPA problem for the downlink MC-NOMA scheme is investigated in [117], which can achieve LDDP-like performance by developing a three-step resource distribution framework to solve the sum-rate maximization issue. The first step of the three-step resource allocation relaxes the problem by supposing each user can employ all subcarriers simultaneously. Then, the problem transforms to convex and solves efficiently via convex programming mechanisms to obtain a power vector for each user. The second step allocates the subcarriers to users in the heuristic greedy manner with the power vectors obtained in the first step. In the third step, the suggested power control strategies used in the first step adjust to optimize the final system execution. Furthermore, a low-complexity UP coupled with a dual-layer PA approach for MC-NOMA systems is presented in [118] with the constraint of user fairness to get a compromise between EE and SE. In addition, the Lagrangian multiplier approach is used to solve the inner layer intra-subchannel PA. On the other hand, an iterative scheme relied on the bisection way is used to resolve the outer layer. In [119, 120], the UPPA issue in the downlink NOMA system is handled by introducing a novel technique called (NOMA-PKKT-HNG), which maximizes the system sum rate. Furthermore, the PA issue is solved by employing Karush–Kuhn–Tucker (PKKT) conditions, and the UP issue is solved using the Hungarian (HNG) algorithm. The user association techniques and closed-form approaches for PA for NOMA system-based multi-cell networks are investigated in [121] to improve the total sum rate and outage probability. Thus, two-game theory-based techniques, namely the preference relation-based algorithm (PRA) and the simulated annealing-based algorithm (SAA) are presented to achieve a reliable user structure. The closed-form approaches for the

Table 5 Summary of solutions for joint UPPA in NOMA system

Ref	Link Type	Solution Scheme	Main Result(s)/Performance Results
[110]	Downlink NOMA	Closed-form Solution with the PF Goal	The suggested UPPA scheme enhances the performance gains of NOMA over OFDMA related to both efficiency and user fairness with low complexity
[111]	Downlink NOMA	Two Sort-based UP Schemes combined with PA Scheme	The proposed schemes greatly advance the performances of both error probability and SE
[112]	Downlink NOMA	Closed form based on the KKT conditions for PA, and Greedy User Selection Algorithm for UP	The proposed scheme develops the NOMA performance gain
[113]	Downlink NOMA	Optimization UPPA scheme to maximize PF metric constrained with transmit power constraints	The suggested UPPA scheme improves the NOMA system-level throughput performance compared to OMA and reduces complexity
[114]	Downlink MU-NOMA	Lagrangian duality and dynamic programming (LDDP) Method	The proposed UPPA scheme significantly improves the system performance in both throughput and fairness over OMA
[115]	Downlink Single-Carrier NOMA	closed-form approach for the optimal PA and pre-selection-based USS (PSU) scheme for UP	The proposed UPPA scheme attains the optimal performance and reduces the complexity
[116]	Downlink MC-NOMA	Suboptimal iterative resource allocation scheme depending on difference of convex programming	The suboptimal resource allocation scheme attains a near-optimal performance
[117]	Downlink MC-NOMA	The centralized PA scheme depending on projected gradient descent algorithm and two distributed power control strategies based on pseudo-gradient algorithm and iterative water-filling Algorithm	The suggested scheme outperforms the power-controlled OMA scheme and provides equivalent sum-rate performance to the previous near-optimal approach with substantially lower computational complexity
[118]	Downlink MC-NOMA	Optimization with closed-form expression	The proposed scheme offers higher EE and SE with low complexity
[119, 120]	Downlink NOMA	NOMA-PKKT-HNG Scheme	The proposed UPPA scheme attains a higher sum rate in comparison with the Difference of Convex (DC), FTPA, and OFDMA approaches
[121]	Downlink multi-cell NOMA	Two-game theory-based algorithms, specifically, PRA, and SAA	The proposed user association methods and closed-form PA algorithms can improve the sum rate and outage probability greatly
[69]	Downlink Single-Cell MU-OFDMA-NOMA	Greedy algorithm for user grouping and the linear water filling algorithm with the FTPA for the PA	The proposed UPPA scheme has better system capacity and reduced complexity performance
[122, 123]	Downlink MC-NOMA	OPT-JSPA, FPTAS and GRAD-JSPA	The suggested scheme provides fairly close WSR with much less complexity than existing optimal methods
[124]	Uplink NOMA	Dynamics solutions of UP and PA	The proposed UPPA technique can optimize the aggregate capacity while also meeting the paired users' individual target rates
[125]	Uplink NOMA	Decouple the UP and PA Part	The proposed UPPA schemes provide better proportional fairness
[126]	Downlink OFDMA-NOMA	Optimization scheme for Joint UPPA	The suggested UPPA scheme outperforms the OMA in terms of system capacity
[127]	Downlink Single-Cell NOMA	MD-NOMA scheme for UP and joint with control power scheme	The suggested UPPA approach achieves a large increase in terms of the number of paired users and overall throughput achieved
[128]	Downlink NOMA	SA scheme	The SA Scheme performs with adequate reliability and low time complexity in terms of throughput improvement
[91]	Downlink NOMA	The CFM-UPPA scheme	The proposed CFM-UPPA scheme performs better than that of the OMA system with the UP at random

PA issue are derived from two forms of QoS constraints and used in each iteration of the suggested user association techniques.

The user grouping and PA in the OFDM-NOMA system are recognized in [69] to maximize the system capacity. Also, for the user grouping, a greedy algorithm is used to build a subcarrier user grouping approach. On the other hand, the linear water-filling method is joined with the FTPA approach for the PA. Moreover, in [122, 123], a novel scheme for joining UPPA problems is analyzed to address the WSR maximization issue in MC-NOMA with cellular power restrictions. Consequently, three approaches based on single-carrier power control (SCPC) and user selection are employed to tackle the joint UPPA problem (SCUS). These three approaches named the optimal pseudo-polynomial time algorithm (OPT-JSPA), the fully polynomial-time approximation scheme (FPTAS), and the GRAD-JSPA. Further, the dynamics of UP and PA are investigated in [124] to show their effect on sum capacity maximization in the uplink NOMA while achieving specific target rates of paired users.

Additionally, the joint UPPA algorithm in the uplink NOMA is suggested in [125] to enhance the proportional fairness of the users. At first, the optimization problem is solved in a basic scenario, in which the users are distributed within the surface area of only one BS. Later, the algorithm is expanded into a complex scenario in which interfering users are randomly distributed outside the surface area of the BS of interest by a spatial homogeneous Poisson point process (HPPP). The joint UPPA is an NP-hard problem in both scenarios. So, the joint UPPA separates. For the PA part of the basic scenario, the Up divides into three types related to the different relationships between the channel condition and the signal-to-noise and interference constraint. For the UP part of the basic scenario, a probability-based Tabu search UP algorithm is suggested to get the near-optimal UP solution.

An optimization problem involving user selection, subcarrier assignment, and PA is recognized in [126] to optimize sum capacity under a generic proportional user fairness restriction. Thus, at first, user selection is performed depending on the reached capacity-to-fairness-factor ratio of each user. Then, a joint subcarrier assignment and PA algorithm is presented for the pair of users to maximize the sum capacity. The above steps of user selection, PA, and subcarrier assignment is repeated until all the subcarriers are allocated to users. The pairing policy in the NOMA system is studied in [127], where the minimal pairing distance between far and near users is evaluated to enhance massive connectivity. Also, in [127], the UP scheme named Minimum Distance-NOMA (MD-NOMA) is proposed and is relied on the determined pairing distance criterion. Furthermore, in [128], the simulated annealing (SA) is used to improve the PA and execute UP to enhance the throughput for the NOMA system. Also, a mathematical proof is implemented to demonstrate that equal PA can be a near-optimal solution to the subchannel PA problem in the NOMA system. Furthermore, by using the NOMA mathematically verifying, it is proved that the proportional power ratio can be set to a value between 0 and 1 to optimize throughput.

Further, a novel UPPA scheme for capacity and fairness maximization in the NOMA system is considered in [91] and named (CFM-UPPA). The PA algorithm of the CFM-UPPA scheme names capacity and fairness maximization-based PA (CFM-PA). The CFM-PA algorithm was designed as an exponentially decaying function of the ratio of multiplexed users' channel gains. Furthermore, the UP algorithm of the CFM-UPPA scheme names capacity and fairness maximization-based UP (CFM-UP). The CFM-UP algorithm focuses on choosing the user with the highest channel gain per subcarrier as the strong user to maximize the capacity and choosing the user with the nearest lower channel gain to the strong user as the weak user to boost the fairness and capacity.

5 Research challenges and future trends

Although the NOMA system is widely regarded as one of the most essential multiple access techniques for 5G and beyond, there are still several outstanding issues that need to be studied further to progress the NOMA system's execution. As a result, this section briefly surveys some of NOMA's research problems and explores future trends for addressing these issues.

5.1 NOMA with imperfect CSI

The current study of the NOMA system is carried out by assuming a perfect CSI to perform multi-user SIC at the user recipient or resource distribution at BS. Also, this assumption is not a practical approach to realize in the NOMA system. Hence, channel estimation errors exist in the NOMA systems in real-time. As a result, channel estimation errors and inaccurate CSI should be addressed in the theoretical study of the NOMA system. Therefore, in practical NOMA systems, further advanced techniques and algorithms are required to get an ideal channel estimation. [102, 129–132].

5.2 Imperfect SIC implementation

In practical situations during SIC procedures, there is an increment in delay and residual intrusion of previously identified users owing to faulty extraction and discovery.

This causes error propagation in the SIC receiver (i.e., an imperfect SIC receiver) and reduces the NOMA system's execution. As a result, for successful SIC implementation, efficient hardware devices must be built to minimize computing complexity, decrease the latency time, and hence enhance NOMA performance. So, efficient approaches for executing the SIC process in the uplink and downlink NOMA systems are implemented [133–138].

5.3 NOMA based heterogeneous network

A heterogeneous network (HetNet) is a wireless network that uses multiple network architectures and operating systems. Also, it contains nodes with varying coverage areas and transmission capacities. The HetNet can decrease the energy consumption of future wireless networks and enhance users' QoS by emerging small cells into the coverage of macrocells. Real-time NOMA allows various types of networks to share resources. In cooperative communication, NOMA-based HetNet essentially enhances the downlink coverage. In the HetNets, effective heterogeneous cooperative communication methods with NOMA are advised to decrease interference problems and achieve spectrum splitting because there is mutual interference between many users and a limited spectrum resource. Therefore, efficient NOMA-based HetNet needs to implement in various research [139–149].

5.4 NOMA in millimeter wave (mm Wave) communication

Millimeter-wave (mmWave) communications and the NOMA technique are two vital techniques to realize the high data rate demands of 5G and beyond. Because the mmWave band fundamentally appropriates for multi-Gbps 5G wireless technology, NOMA techniques become more attractive at mmWave frequencies. Also, NOMA techniques can increase the achieved data rates while providing concurrent multi-user connections. Despite its potentiality, the utilization of NOMA in mmWave communications is still early and is appropriate in various situations, such as IoT and cloud-helped vehicular systems. Therefore, the NOMA in mm-wave communications recommends promoting a high data rate wireless access in 5G technologies [150–154].

5.5 Visible light communication (VLC) based NOMA

Regardless of mmWave communications, Visible Light Communication (VLC) has received a high concentration in seeing the world of communication through the perspective of good spectrum resources. The VLC allows many features, such as high data rate, high security, eye safety, license-free wide bandwidth, no electromagnetic interference, and low power consumption. Furthermore, the VLC utilizes random data signals to operate light-emitting diodes (LEDs) instead of the incandescent and fluorescent lamps for conventional light senders. So, the VLC is considered a great approach to 5G networks and beyond. Also, the VLC system performance can be enhanced using the NOMA system. So, much research needs to be executed on the NOMA VLC system to make VLC-based NOMA beneficial in different conditions and positions [155–159].

5.6 NOMA-based mobile edge computing (MEC)

Mobile edge computing (MEC) is considered one of the 5G technology's enabling technologies. The MEC technology allows user equipment (UEs) to perform many compute-intensive applications by producing computing abilities at the network edge and within wireless access networks. Furthermore, the NOMA systems permit several UEs to participate in the same resources. Thus, the combination between the NOMA system and MEC technology leads to many benefits, such as lower energy consumption, improved EE and SE, and an increase in the number of corporative UEs. Therefore, it is necessary to recommend a NOMA-based MEC in various studies [160–169] to solve big data processing in future 5G wireless networks.

5.7 Practical realization of more than two-user pairing

The main feature of the NOMA system is that it serves several users in the same resource. However, most practical studies adopt a two-user pairing strategy to make getting the channel gains of two-paired users at the BS easy and implementing effective SIC at receivers more manageable. New approaches for multi-user pairing are also necessary as the demand for linked devices such as IoT, machine-to-machine (M2M), and enormous machine-type communications grow. These multi-user pairing approaches need to take full advantage of NOMA into account. Hence, multi-user pairing techniques increase mass connectivity that meets the requirements of the upcoming wireless network.

5.8 Hybrid NOMA

Connecting trillions of devices through a central BS becomes challenging, especially in the lower SNR regimes due to restricted possible orthogonal resources with very low-latency wireless links. Therefore, it seems that the NOMA scheme is not very proper for this issue. Accordingly, a hybrid MA that relies on a combination of NOMA and OMA techniques considers a better way to link huge devices in IoT scenarios, D2D, M2M communications, and so on, to overcome this issue. The hybrid NOMA utilizes both PD-NOMA and CD-NOMA for MA. Further, the hybrid NOMA provides a higher SE compared to the NOMA and the OMA techniques. So, the hybrid NOMA can switch between NOMA and OMA operation techniques and can implement in various research [170–175].

5.9 IoT and MIMO-NOMA

The internet-of-things (IoT), which represents the connectivity of everything everywhere, is one of the main structures of the 5G technology. The massive MIMO and NOMA combination is applied to cellular IoT to support the massive connectivity of IoT devices with a restricted radio spectrum. Therefore, Massive MIMO-NOMA provides high throughput efficiency and system scalability to support a large number of devices with simple system architecture, which is profitable for massive IoT applications with low cost, power, and complexity devices. Thus, new techniques with an optimal multi-objective design are required to prove the influence of MIMO-NOMA on the achievement of IoT needs [176–180].

6 Conclusion

The NOMA scheme is hugely beneficial in recent advances in the 5G technology and beyond. Accordingly, this paper furnishes the reader with a summary of the NOMA system and explores the future trends that make it an essential paradigm for the 5G technology and beyond. Therefore, firstly, a survey of the multiple access techniques and their classifications is presented. Then, the fundamentals of the NOMA scheme with its system model of multi-user transmissions are reviewed. Also, the benefits and weaknesses of the NOMA system are studied in comparison with the OMA system. In addition, this paper comprehensively surveys the resource allocation issues of the NOMA system related to UP, PA, and joint UPPA. Various solutions to resource allocation issues of the NOMA system are classified and summarized in the literature. Finally, the future research challenges of the NOMA system and beyond are explored and presented.

Acknowledgements The authors would like to acknowledge the support received from Taif University Researchers Supporting Project Number (TURSP-2020/147), Taif university, Taif, Saudi Arabia.

Funding This research was supported by Taif University Researchers Supporting Project Number (TURSP-2020/147), Taif university, Taif, Saudi Arabia. Furthermore, this research was supported by the H2020 Marie Skłodowska-Curie Actions (MSCA) Individual Fellowships (IF) IUCCF grant 844253.

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