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Review of the Non-Orthogonal Multiple Access in 6G Technologies: Applications, challenges, and Future Directions

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Abstract

This survey synthesizes state of the art advancements of Non-orthogonal multiple access (NOMA) in 6G technologies, NOMA has emerged as a highly promising approach for increasing user capacity, enhancing spectral efficiency, and promoting user fairness in wireless networks. The former can achieve high spectral efficiency by modulating the information in power domain and the latter can provide extremely large spectrum resources. By enabling a multitude of users to share the same set of wireless resource, NOMA provides a significant departure from traditional access methods. Its flexibility allows seamless integration with various traditional and innovative wireless technologies, such as millimeter-wave communications (mmwave), massive multiple-input multiple-output (massive MIMO), heterogeneous networks, unmanned aerial vehicles (UAV), integrated sensing and communication (ISAC), and reconfigurable intelligent surfaces (RIS). Integrating NOMA with these innovations can significantly improve energy efficiency, spectral efficiency, scalability, and the sustainability of future communication networks. This review paper presents a detailed review of the interaction between NOMA and these technologies, highlighting the mutual benefits of their integration. Additionally, it identifies key challenges and outlines potential future research directions to further develop and optimize NOMA-enabled systems.

Keywords: *NOMA, mMIMO, mm wave, HetNets, UAV.*

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1. Introduction

Wireless cellular networks have emerged as a transformative technology, enhancing daily life and fueling economic growth. With the rapid advancement of mobile applications, the increasing prevalence of smart wireless devices, and the rising demand for Internet services and multimedia applications such as video streaming and online gaming, next-generation mobile access systems like 5G and beyond are being developed to accommodate these expanding connectivity needs. This evolution highlights the growing importance of optimizing spectrum efficiency. Industry forecasts indicate that cellular Internet of Things (IoT) connections could surpass 5 billion by 2030, while the number of mobile subscriptions is projected to reach approximately 9.4 billion in the same period (Li et al., 2025). Additionally, global mobile data traffic is expected to surge, with 6G networks anticipated to carry around 80% of total traffic by 2030. Although exact figures for monthly data consumption vary, mobile video is predicted to remain the largest contributor to overall data usage (Current Forecast Highlights - Transforma Insights, n.d.).

The advent of 5G and B5G technology demands superior capabilities, including higher spectral efficiency, reduced latency, and enhanced network capacity. These requirements will become even more critical with the evolution of 6G networks, which aim to address diverse user needs. To meet these demands, a novel access technique called Non-Orthogonal Multiple Access (NOMA) has emerged, garnering significant interest from the research community. Unlike traditional orthogonal multiple access (OMA) methods, where only one user can occupy a resource at a time (Goyal et al., 2017), NOMA allows multiple users (MUs) to share the same time and frequency resources simultaneously. This approach enhances spectral efficiency and optimizes resource utilization (Islam et al., 2017).

Historically, cellular networks (1G to 4G) relied on orthogonal access methods, such as frequency division multiple access (FDMA), time division multiple access (TDMA), code division multiple access (CDMA), and orthogonal frequency division multiple access (OFDMA). These methods allocated distinct resources—whether frequency, time, code, or space—to users, simplifying receiver design and preventing inter-user interference. However, this orthogonalization approach limited the number of users to the available resources, which becomes a significant bottleneck in 5G's era of massive connectivity. OMA's limitations extend beyond user capacity. In addition, as the number of orthogonal resources is limited, the OMA systems cannot serve a large number of users, as imposed by 5G(Islam et al., 2019). It has been theoretically proven that OMA cannot always achieve the maximum attainable rate for multi-user wireless systems.

As a result, 5G networks must accommodate a large number of devices with varying throughput and latency requirements. This need is further amplified by the rapid growth of Internet of Things (IoT) devices, which are expected to grow annually by 20–30% in the coming years. The International Telecommunication Union (ITU) has set ambitious performance targets for 5G under IMT-2020, including 100 times the connection density of 4G, alongside high data rates, low latency, low power consumption, and expanded system capacity. NOMA is well-suited to meet these challenges by supporting massive connectivity and achieving multi-user capacity through techniques like timesharing or rate-splitting (Vaezi et al., 2019).

6G is now the current wireless communication technology in development, a gradual evolution from the initial 1G. When comparing all generations, it is clear that the internet speed and coverage increase gradually. The 6G target is to provide global coverage. AI applications will distinguish 6G from previous generations. Although it is still in its early stages, the autonomous 6G network is expected to serve as the backbone of 6G technology. Compared to the current 5G capacity, data rates and security quality will increase, and latency will decrease. 6G is estimated to have a speed of 1–10 Tbps (Khiadani et al., 2020) and efficient use of scarce spectrum resources is required. Its frequency will be higher than all other generations. The frequency generally increases as generations move forward. High transmission rates are indicated by the THz frequency. Because of 6G, latency will be in the range of 10–100 µs, connectivity density will be in the range of 10 devices/km2, NOMA's non orthogonal design enables simultaneous access for thousands of devices. Also traffic capacity will be in the range of 1 Gb/s/m2 (Khiadani et al., 2020).

A defining feature of NOMA is its ability to serve more users than the number of orthogonal resources available. Two primary resource allocation techniques under NOMA are Code Domain NOMA (CD-NOMA) and Power Domain NOMA (PD-NOMA). PD-NOMA enables multiple users to share the same frequency band simultaneously by allocating different power levels, thereby increasing the number of users served within a single time slot. However, this comes with the tradeoff of increased receiver complexity (Islam et al., 2017). In contrast, CD-NOMA, inspired by the CDMA used in 3G networks, assigns unique codes to users for simultaneous data transmission. A comparison between CD-NOMA and PD-NOMA is presented (Moltafet et al., 2018).

This paper primarily focuses on the PD-NOMA technique. The NOMA scheme implements power modulation by allocating higher power to signals transmitted to users with worse channel conditions. At the destination, multiple users receive the superimposed signal, where the signal with the highest signal-to-interference-plus-noise ratio (SINR) is decoded first, and other signals are treated as interference. In other words, receivers with better channel conditions decode signals using a technique called successive interference cancellation (SIC), while receivers with worse conditions decode their information directly. Figure. 1 shows transmit power levels in PD-NOMA.

1.1. How NOMA works

In the NOMA downlink, the BS transmits overlapping information signals to its served users. To decode their respective signals, each user (i) employs SIC. Figure. 2 illustrates the BS and 2 users employing SIC. The user closest to the BS is denoted as U1, while the farthest user in the network is represented as U2. The NOMA framework allocates the full system bandwidth (B) to all served users (I), utilizing N_j subcarriers. To mitigate the inter user interference for users sharing the same subcarrier, the NOMA system employs SIC. On the j^{th} subcarrier (where j ∈ {1, 2, ..., N_j}), the BS transmits the signal $S_{i,j}$ to the i^{th} user (where i ∈ {1, 2, ..., I}). The received signal $x_{i,j}$ at the i^{th} user on the j^{th} subcarrier is then processed accordingly.

$$x_{i,j} = \underbrace{h_{i,j} S_{i,j}}_{\text{required signal}} + \underbrace{h_{i,i} \sum_{t=1,t\neq i}^{I} S_{t,j}}_{\text{Inter-user interfarence}} + \underbrace{z_{i,j}}_{\text{Noise}} \quad (1)$$

Where, $S_{i,} = \alpha_{i,j} P_i q_{i,j}$, while $q_{i,j}$ and P_i are, the information signal at power normalization and the transmitted power from a single cell BS for i^{th} user on j^{th} subcarrier, respectively. The factor $0 \leq \alpha_{j,i} \leq 1$ is the PA factor at $US_{i,j}$. The parameter $h_{j,i}$ is the channel between i^{th} user on j^{th} subcarrier and the served BS, while $z_{j,i}$ is recognized as additive white Gaussian noise (AWGN) with noise power (variance) σ^2.

The implementation of NOMA in the uplink differs significantly from its downlink counterpart. Figure. 3 illustrates a network utilizing NOMA in the uplink. In uplink NOMA transmission, users must initially send a control message to the BS, which contains PA information. Unlike in the downlink, the BS now employs SIC to distinguish between user signals. Hence, for optimal detection, the BS first decodes the strongest received signal before proceeding to weaker signals in sequential order. The signal received by the BS that encompasses all user signals as

$$x_k = \underbrace{h_k s(t)}_{\text{required signal}} + \underbrace{z_k(t)}_{\text{Noise}} \quad (2)$$

where h_k represents the factor of channel attenuation for the link between the BS and the i^{th} user and $z_k(t(t)$ represents the additive white Gaussian noise at the i^{th} user with mean zero and density N0 (W/Hz).

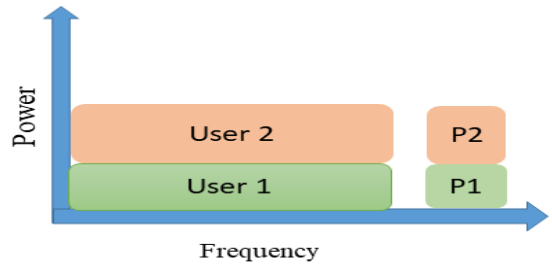

Figure 1. Transmission power levels in NOMA system.
Source: (researcher)

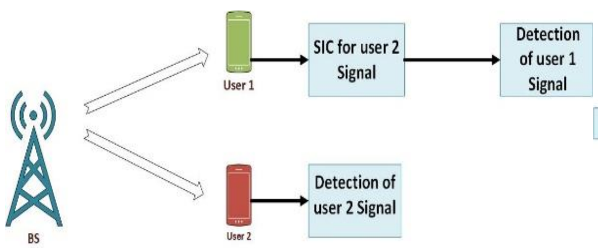

Figure 2. Downlink NOMA System.
Source: (researcher)

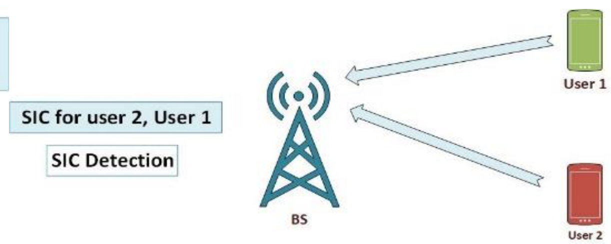

Figure 3. Uplink NOMA System.
Source: (researcher)

2. Application of NOMA in 6G Technologies

By enabling multiple users to share a single resource block via power multiplexing, NOMA significantly increases system capacity and enhances the system Performance. NOMA can be seamlessly integrated with various other current and future technologies, such as massive multiple-input multiple-output (mMIMO), millimeter wave, heterogeneous networks (HetNets), reconfigurable intelligent surface (RIS), and integrated sensing and communication (ISAC). By combining NOMA with these innovations enhance the system performance in various senses.

2.1. NOMA and mMIMO

Massive MIMO has the ability to significantly enhance the spectral efficiency in telecommunication through advanced spatial multiplexing techniques (Marzetta et al., 2010)–(Larsson et al., 2014). Extensive research on massive MIMO with orthogonal multiple access (OMA) has shown that the highest spectral efficiency is achieved in under loaded systems, particularly when linear processing is utilized at the base station (BS). For example, with maximum ratio zero-forcing (ZF) combining (MR) combining, the optimal spectral efficiency occurs when the is approximately 2 to 5 times smaller than the antennas number (Björnson et al., 2016). As a result, massive MIMO-OMA may struggle to assist in handling systems under heavy load, where the users number surpasses the available antennas at the BS. In contrast, massive MIMO with NOMA offers significant potential to overcome this limitation, enabling it to meet the massive connectivity demands of future wireless networks while further boosting the spectral efficiency of NOMA-based systems (Senel et al,. n.d.). Figure. 4 shows NOMA inspired massive MIMO, where BS transmits data using Massive MIMO to multiple clusters. Within each cluster, users are grouped based on certain criteria (channel conditions, QOS), NOMA allows multiple users to receive signals over the same frequency/time resources. Then SIC is applied at users to decode their signals efficiently. This process repeated for each transmission cycle, optimizing spectrum efficiency and system capacity.

(Chandra et al., 2022) focuses on maximizing the implementation of a THz-NOMA-MIMO system. The proposed approach effectively enhances power efficiency by mitigating interference in data communication, thereby enhancing both spectral and power efficiency. (Wei et al., 2022) study a design problem as to how to enhance the spectral efficiency and energy efficiency at the same time, and for developing resource allocations scheme for hybrid TDMA-NOMA. This provided extra freedom in resource allocation. This configuration was defined as a non-convex problem, i.e., multi-objective optimization (MOO). The issue of MOO was reformulated as an issue of single objective optimization by combining the multi-objective through a weighted sum objective function. In that design, every objective received a weight factor to indicate its significance. To tackle the non-convexity originated from the concept of extreme risk measures, we jointly leveraged the second-order cone and sequential convex approximation. (Zhang et al., 2020) focused on improving energy efficiency on the THz-NOMA-MIMO system. For user clustering within the THz-NOMA-MIMO framework, an advanced K-means machine learning algorithm was formulated. Utilizing the sub-connection structure, a hybrid precoding scheme was implemented. To facilitate power allocation, a distributed alternating direction method of multipliers was devised, thereby optimizing the energy efficiency of the THz-NOMA system. (Ye et al.,2020) introduced a mmWave NOMA-MIMO technique that relies on beam aggregation. The application of NOMA within MIMO systems can significantly improve both spectral efficiency and throughput. Earlier studies on NOMA MIMO technology focused on the principle of serving multiple user equipment (UEs) via a single beam. In the newly proposed strategy based on beam aggregation, a greater number of UEs are accommodated through a collective set of beams. (Simon et al., 2023) suggested an innovative approach to sub-band allocation and user pairing for a densely populated downlink (DL) system, leveraging a criterion focused on reducing the condition number (CN) of channel matrices. Additionally, a benchmark resource allocation method is introduced, which employs a rate maximization criterion. While this benchmark technique offers quasi-optimal performance, it comes with higher computational complexity. To assess the effectiveness of the proposed approach in practical scenarios, experimental massive MIMO channel measurements are utilized within a densely deployed user environment. (Jayasinghe et al., 2024) analyzes the achievable rates for DL and UL communication in RIS -aided massive MIMO systems employing NOMA. A linear minimum mean square error (LMMSE) technique is applied to estimate UL composite channels at the massive MIMO base station, based on user pilots and a predefined RIS phase-shift matrix. To optimize the RIS phase-shifts, a statistical CSI-based approach is adopted, utilizing effective covariance matrices of composite channels corresponding to NOMA clusters with distinct spatial characteristics. By exploiting the slower variation of channel statistics relative to the channel coherence interval, significantly this method reduced pilot overhead and computational complexity.

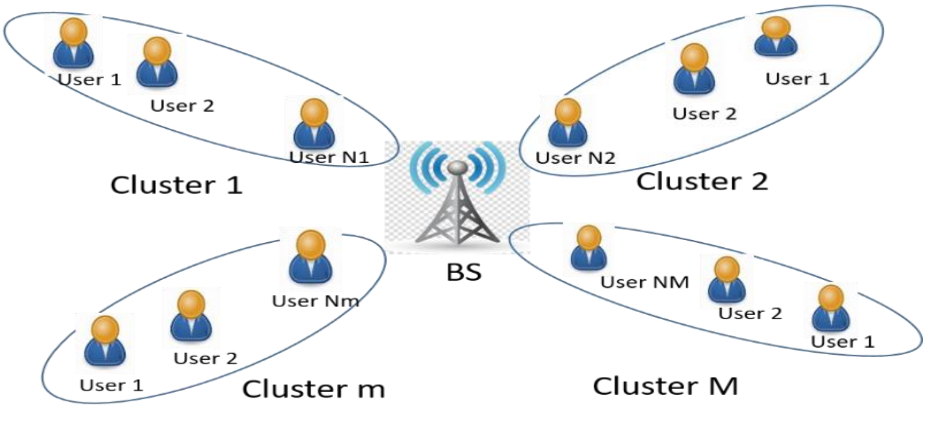

Figure 4. NOMA inspired mMIMO.
Source: (researcher)

2.2. NOMA in mmWave/THz Bands

To meet the extremely high data rate demands of B5G wireless networks, communication within the millimeter wave (mmWave) spectrum (30 GHz to 300 GHz) These frequencies correspond to wavelengths in the millimeter range (1-10 mm), hence the name. Due to the small wavelength, mmWave systems can implement large antenna arrays and thus enabling advanced techniques like spatial multiplexing. This allows multiple data streams to be transmitted simultaneously in the same frequency band, increasing spectral efficiency. MmWave communication has garnered significant interest over the past decade. Both theoretical and experimental studies have demonstrated that mmWave bands can Gbps data rates due to the large available bandwidth (e.g., up to 2 GHz in the 60 GHz band) (Rappaport et al., 2014), (Heath et al., 2016). However, mmWave channels are sparse in the spatial and angular domains, which Restricts the number of concurrent connections at these superior frequencies. By integrating massive MIMO-mmWave with NOMA, this limitation can be addressed. Figure. 5 shows mm-wave NOMA downlink system, where RF prepares the signal for transmission over the mmWave frequency band. The signal is then sent to multiple phase shifters, which adjust the phase of the signal for each antenna element. this phase adjustment is crucial for analog beamforming, allowing the system to steer the signal toward the intended users efficiently. The phase-shifted signals are then amplified using a power amplifier to ensure sufficient transmission power. mmWave signals suffer from high path loss, so power amplification is essential for long-range transmission. The phase-shifted signals are then amplified using a power amplifier to ensure sufficient transmission power. mmWave signals suffer from high path loss, so power amplification is essential for long-range transmission. Then applying PD-NOMA to the users

The negative effects of beam misalignment in NOMA mMIMO mmWave systems with hybrid beamforming have been explored (Almasi et al., 2019). The optimal analog and digital precoders were designed to maximize the sum rate. To achieve this, a lower bound for the achievable sum rate was derived in closed form, assuming perfectly aligned LoS channels. The influence of misaligned Line of Sight (LoS) or Non-Line of Sight (NLoS) channels was incorporated by introducing a carefully designed beam misalignment factor. Subsequently, the lower bound of achievable user rates under beam misalignment was calculated. Lastly, an upper bound for the rate gap between perfectly aligned and misaligned beams was established. Thus, it has been concluded in (Almasi, et, al., 2019) that the achievable rates can be significantly impacted when imperfect designs of analog/digital precoders lead to beam misalignments in NOMA mmWave mMIMO systems (Wang, et al., 2017). NOMA has been integrated with mmWave MIMO systems utilizing lens antenna arrays (Wang, et al., 2017) and (Almasi, et, al., 2019). These techniques enable simultaneous service to more users than the number of available RF chains. Lens antenna arrays convert traditional spatial MIMO channels into the beamspace domain through a discrete Fourier transform (Brady, et, al., 2013). Achievable rates were derived, guiding the design of precoders to reduce inter-beam interference and the creation of transmit power control algorithms. To optimize the achievable sum rate, a dynamic power allocation strategy was introduced to minimize both intra- and inter-beam interference. This power allocation challenge was tackled using a low-complexity iterative optimization algorithm. Additionally, efficient beam selection algorithms in the beamspace domain demonstrated that combining NOMA with beamspace mmWave MIMO significantly improves both spectral and energy efficiency (Wang, et al., 2017). (Aghdam et al., 2022) presents an optimal approach for joint PA and beamforming in MIMO-NOMA systems operating in mmWave communications. They adopt a random near-random far (RNRF) pairing strategy for NOMA data transmission to minimize system overhead. The convexity of the optimization problem is rigorously established, and an iterative algorithm is presented to jointly update the PA and RBF coefficients, maximizing communication reliability. This method demonstrates a significant reduction in the system's outage probability (OP). The potential of large-scale distributed transmission to enhance NOMA performance was examined (Li et al., 2018),(Zhu et al., 2019). Specifically, (Li et al., 2018) derived the achievable rates for a NOMA-enabled cell-free massive MIMO system, accounting for beamforming inaccuracies and residual interference caused by imperfect channel estimation and SIC operations Ample bandwidth due to using mmWave frequencies, also using multiple antennas in massive MIMO technology enhanced system capacity and signal quality. Singular Value Decomposition (SVD) beamforming is used instead of Zero Forcing (ZF) due to the condition that users count does not exceed the available beam count. In beam space NOMA-massive MIMO systems, where user count usually outnumbers available beams, this becomes a limitation. By comparing the hybrid structure with full digital structure, the first one balances energy consumption and throughput highlighting the efficiency of NOMA in supporting a large number of users with a limited number of RF chains. Hence, for high SE values, the hybrid structure significantly impacts energy consumption when compared to a fully digital setup. In a full digital configuration, the number of RF chains needed matches the number of antennas, which are key contributors to energy consumption. Briefly NOMA with massive MIMO and mmWave could bolster both spectral and energy efficiencies (Oubassghir et al., 2024). In terms of ergodic capacity (EC) and outage probability (OP), the performance of NOMA-based mmWave communication systems is considered (Oubassghir et al., 2023). The suggested scenario is that one single antenna base station BS serves two users simultaneously under NOMA scheme. Considering two different PA schemes, fixed PA and optimal PA. The second scheme achieved the maximum sum rate. (Yan et al., 2024) introduced a communication framework that integrates mmWave technology with NOMA to enhance both data transmission capacity and security of vehicular communications with Artificial Noise (AN) injection, supported by advanced beamforming and stochastic modeling techniques.

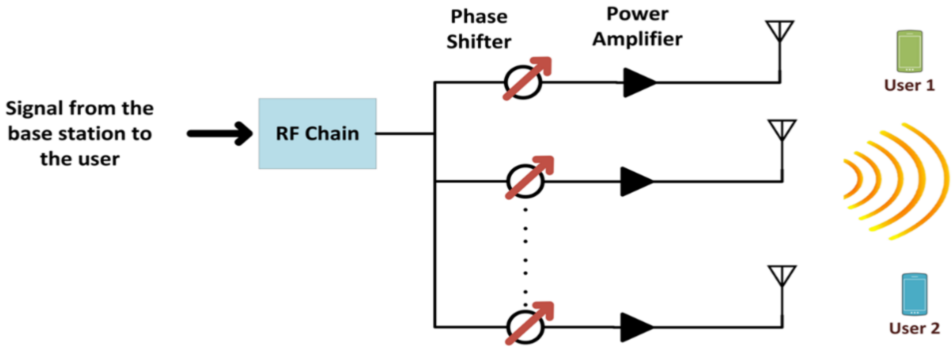

Figure 5. NOMA-mmwave downlink system.
Source: (researcher)

2.3. NOMA in HetNets

Heterogeneous networks (HetNets) play a significant role in increasing spectral efficiency in cellular networks and wireless communication systems. It consists of a mix of macro cell (MC) (large base station) and small cells (SC) (such as microcells, pico cells, and femto cells). SCs are deployed in areas with high traffic to provide better coverage and offload traffic from macro cell. This densification increases the reuse of frequency spectrum within the same geographical area. Also HetNets enable aggressive frequency reuse by allowing SCs to operate on the same frequency band as larger MC without causing significant interference. Since SCs cover smaller areas, they can reuse the same frequencies in different locations which leads to better utilization of the available spectrum and, ultimately, higher spectral efficiency. Nevertheless, unfavorable interference between SCs and MC will arise from the reuse of the available resource blocks (RBs), such as time and frequency. Interference management is considered as a crucial research topic that needs to be solved in HetNets since interference restricts the capacity that can be obtained by the networks (Zhao et al., 2017). For instance, interference must be controlled, possibly by changing the transmit power levelsof the nodes. Additionally, in order for the network to make accurate mobility decisions when nodes are deployed haphazardly, it must acquire intelligence about the network topology, specifically identifying which nodes are close to one another (Chapman et al., 2014). Figure .6 shows interference that are considered in the heterogeneous signal to interference plus noise ratio (SINR) computation with NOMA system. Interference between cells of the same kind is known as co-tier interference, and interference between cells of different types is known as cross-tier interference.

(Nasser et al., 2023) introduced an energy-efficient approach for managing interference in heterogeneous networks (HetNets) operating with DL-NOMA in mmWave. The presented method employs a data-driven (DD), resource block (RB) and power allocation strategy to enhance the network's EE while mitigating inter-user, co-tier, and cross-tier interference. The interference management problem is formulated as an optimization task aimed at maximizing EE in NOMA-HetNets, subject to constraints such as SIC conditions, QOS requirements, maximum PA, and the capacity limitations of individual RBs. (Muhammed et, al., 2023) explores NOMA-HetNets in mmWave communications, consisting of macro-cell and small-cell tiers connected via a wireless backhaul. To streamline the user clustering process, introducing a user grouping algorithm that forms clusters of highly correlated users, effectively reducing inter-cluster interference is considered. Additionally, a hybrid analog/digital precoding scheme at the macro base station is suggested to enhance system performance. The primary objective was to maximize the total EE of the NOMA HetNet by jointly optimizing hybrid precoding, power allocation, and bandwidth partitioning. Hence, the optimization problem subjected to some constraints like minimum data rate and total transmission power. Given its non-convex nature, deriving an optimal solution is computationally complex. This problem is transformed into a quasi-convex equivalent by analyzing the structure. Also, for optimizing resource allocation across macro and small cells, energy-efficient distributed power allocation algorithms is developed. Maximizing energy efficiency (EE) through user equipment (UE) clustering (UE-C) in downlink hybrid NOMA (DL-H-NOMA)-assisted beyond 5G (B5G) heterogeneous networks (HetNets) is achieved. The optimization problem integrates UE admission within clusters, UE association with base stations (BS), and power allocation using hybrid NOMA (H-NOMA), incorporating both NOMA and OMA schemes in macro base stations (MBS) and HetNet environments. The formulated problem belongs to the class of non-linear concave fractional programming (CFP) problems. By applying the Charnes-Cooper transformation (CCT), this problem is converted into a concave optimization problem, specifically a mixed-integer non-linear programming (MINLP) problem. Also, by employing a two-phase ε-optimal outer approximation algorithm (OAA) the MINLP problem is solved (Ghafoor et al., 2022). Data Driven (DD) is used as an optimization tool with NOMA-HetNets. The main goal to maximize the sum rate, and mitigating the interferences such as inter user interference between NOMA users, and cross tier interference due to HetNets. By optimizing the resource block allocated to the NOMA users and the allocated power over HetNets base stations (BSs). The formulated problem considers QOS and SIC (Mohamed et, al., 2022). Interference mitigation and power allocation (PA) scheme, termed PA-based Interference Alignment and Coordinated Beamforming (PA-IA-CB), is proposed for DL-MIMO-NOMA HetNets. The scheme effectively managed the interference (co-tier and inter-cluster interference among small cells (SCs) and cross-tier interference between the macro base station (MBS) and small base stations (SBSs)) and optimizes power allocation to enhance the system sum rate. The performance of PA-IA-CB is evaluated against MIMO-OMA and MIMO-NOMA HetNets, showing significant improvements in outage probability and system sum rate across different SNR levels and coverage distances (Nasser et, al., 2019).

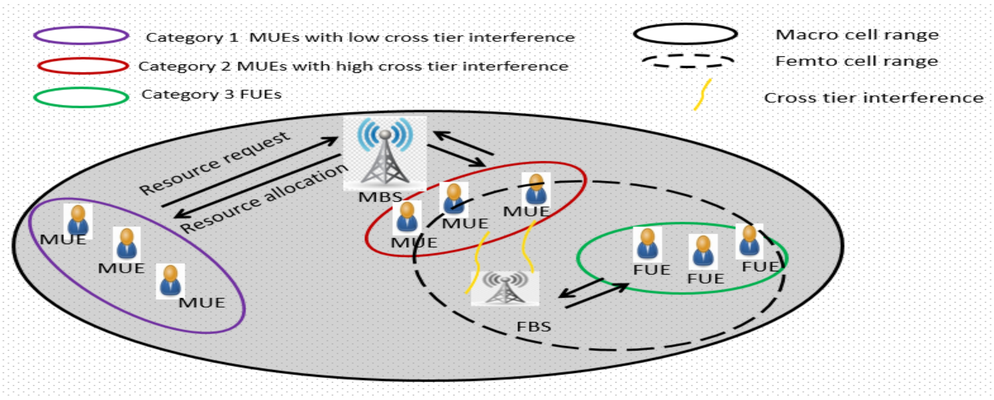

Figure 6. NOMA Heterogeneous network with considered types of interference.
Source: (researcher)

2.4. NOMA with non-terrestrial BS (UAVs)

An aircraft without a human pilot, crew, or passengers on board is referred to asan unmanned aerial vehicle (UAV), or drone for short. Originally designed for military tasks deemed too “dull, dirty, or dangerous” for human personnel, unmanned aerial vehicles (UAVs) became a vital tool for the majority of militaries at the turn of the twenty-first century.

Figure.7 shows UAV connection in a cellular system. UAVs can be installed aboveterritorial devices at a reasonable altitude with line-of-sight (LOS) links; thus, compared to traditional territorial wireless networks (TWNs), the UAV-aided wireless network can offer higher data rates and better coverage. UAVs can support traditional communication networks by acting as flying base stations (UAV-BSs) and managing traffic demand. While standard base stations are permanent and stationary, a UAV flying base station uses mobility functionality to better support mobile consumers. Although this mobility offers a chance to better serve the user (by getting closer to them for higher channel dependability and data transfer rate/bandwidth), it also brings with it special hazards and engineering challenges. Its user-dependent mobility control is unique since flyingbase station research and development is still in its early stages (Lagkas et al., 2018).

(Azam et al., 2022) introduced a UP and PA strategy to optimize EE and ensure QOS in NOMA-based UAV networks, accommodating both cellular-connected mobile UAVs and ground users (GUs). Minimizing energy consumption was the essential objective during uplink transmission while maintaining the required data rates for aerial users (AUs) and GUs through efficient pairing and PA. To achieve this, a joint pairing and power optimization problem is formulated as a nonconvex optimization challenge under QOS constraints. UP complexity is compared to traditional NOMA pairing and PA methods based on channel conditions and power consumption, and the improvements in EE efficiency, outage probability are validated. Joint optimization of the wireless power transfer (WPT) time, multi antenna UAV transmit power, NOMA power allocation coefficient, and UAV location was proposed to maximize the system EE. This problem is a non-convex problem. hence, the problem was divided into three sub-problems using block coordinate descent (BCD) method to overcome the non-convexity. The first part addresses power allocation within each NOMA user pair using a super-modular game-based method, which ensures convergence to a stable solution (Nash equilibrium). The second part optimizes power allocation between user pairs and WPT time using successive convex approximation (SCA). Lastly, the optimal placement of the UAV is calculated using the Lagrange multiplier method. This step-by-step approach effectively enhanced the system's energy efficiency (Wang et, al., 2022).

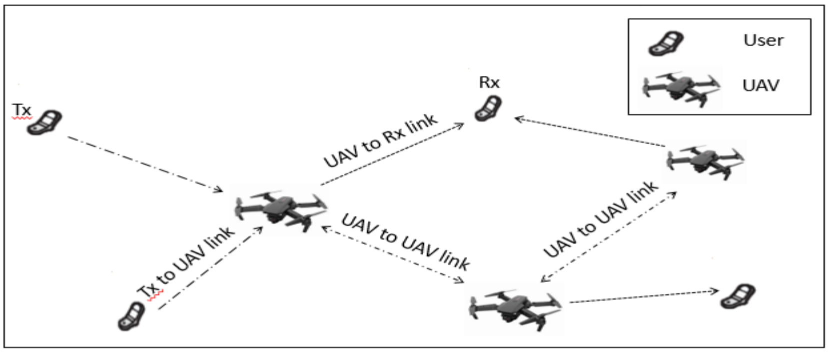

Figure 7. UAV connection in a cellular communication system.
Source: (researcher)

The integration of CR and NOMA within the UAV-assisted cooperative framework significantly improves SE by allowing more users to be served simultaneously with better utilization of available spectrum resources. Utilizing UAVs as relay nodes enhances network coverage and reliability, particularly in areas where traditional terrestrial infrastructure is inadequate or absent. The study also identifies challenges such as increased system complexity, potential interference management issues, and the need for efficient resource allocation strategies to fully realize the benefits of the proposed system. Identifying practical challenges in implementing the presented framework, such as: interference management in NOMA, efficient PA for users with varying channel conditions, and The impact of UAV mobility and positioning on system performance (Chu et al., 2024) A hybrid algorithm, combining Continuous Genetic Algorithm and Particle Swarm Optimization (CGA-PSO), has been developed to optimize NOMA power allocation and configure UAV relays (URs) for achieving maximum throughput of NOMA-based CR system with UAV-assisted relays under the constraints of primary network performance and security (Dang et al., 2022). Furthermore, a communication protocol has been introduced, featuring an energy harvesting (EH) phase and multiple communication. (Wu et al., 2025) presents a NOMA-based multi-UAV-assisted D2D communication framework, where multiple UAVs function as airborne BSs to facilitate communication among ground-based cellular users and D2D clusters. To enhance system throughput, the study formulates an optimization problem integrating joint channel assignment, trajectory planning, and power control. To address this challenge, a Joint Dynamic Hypergraph Multi-Agent Deep Q Network (DH-MDQN) algorithm is introduced. Initially, a dynamic hypergraph approach is applied to construct and transform dynamic edges and hyper edges into directed graphs, enabling efficient dynamic coloring for optimized channel allocation. Subsequently, trajectory planning and power control are modeled as a multi-agent Markov Decision Process (MDP), with the Multi-Agent Deep Q Network (MDQN) algorithm employed to collaboratively optimize UAV position and PA. Simulation results validate the effectiveness of the proposed approach, demonstrating superior system throughput compared to benchmark algorithms under various conditions, including different D2D cluster densities, communication distances, and UAV fleet sizes. Additionally, the optimized 3D trajectory design achieves a 27% increase in system throughput over conventional 2D trajectory planning, while the incorporation of decoding order constraints in the NOMA scenario leads to an average 34% improvement in overall performance. These findings highlight the potential of integrating NOMA with UAV-assisted D2D communication to enhance SE and network capacity in next-generation wireless systems. (Hosny et al., 2024) explores the integration of UAVs with NOMA by developing advanced power allocation (PA) and trajectory planning algorithms (TPAs). The research models the problem as a budgeted multi-armed bandit (BMAB) framework to optimize UAV flight paths while minimizing energy consumption. In this framework, UAVs are considered "bandit" players, while clusters of disaster zones represent "targets." The solution is derived using two upper confidence bound (UCB) algorithms. Compared to conventional UAV-OMA systems, this approach enhances the number of assisted survivors by 60%, accelerates convergence speed by 80%, and significantly reduces energy consumption. Additionally, the literature (Amhaz et al., 2024) investigates the UAV-assisted NOMA downlink scenario, further highlighting the potential benefits of integrating UAVs with NOMA. Table 1, summarizes integrating NOMA with mMIMO, mm-wave and UAV.

2.5. NOMA with RIS

Reconfigurable Intelligent Surfaces (RIS) is an emerging wireless communication technology that enhances signal propagation by intelligently reflecting signals to non-line-of-sight (NLOS) users and manipulating electromagnetic waves. It consists of a large array of passive, tunable elements that can dynamically adjust their phase shifts to improve wireless signal transmission and suppress interference and the inter-user interference in NOMA, improving the utilization of available spectrum and SE of NOMA-based systems and enhancing SIC performance. Unlike conventional active relays, it operates passively without requiring power-intensive RF chains, significantly reducing energy consumption. It is energy-efficient and cost-effective. By strategically placing RIS in a communication environment (e.g., on buildings, walls, or

UAVs), wireless networks can overcome obstacles, mitigate interference, and enhance coverage. It can help NOMA systems to support more users and achieve higher overall throughput.

TABLE 1: Summary of integrating NOMA with mMIMO mm wave and HetNets.

Author	Main contribution	Criteria
Chandra et al. (2022)	THz-NOMA-MIMO system for power efficiency maximization.	Mitigating the interference in data communication.
Wei et al. (2022)	Enhancing SE and EE in hybrid TDMA-NOMA systems.	Resource allocation scheme for hybrid TDMA-NOMA, multi-objective optimization for energy and spectral efficiency. (SOCP and (SCA) are used to address non-convexity.
Zhang et al. (2020)	Energy efficiency improvement on THz-NOMA-MIMO systems.	Optimization problem is divided into user clustering, hybrid precoding and power optimization. Based on channel correlation characteristics, a fast convergence scheme for user clustering in THz-NOMA-MIMO system using enhanced K-means machine learning algorithm is proposed. Considering the power consumption and implementation complexity, the hybrid precoding scheme based on the sub-connection structure is adopted..
Ye et al. (2020)	Beam aggregation.	mmWave NOMA-MIMO with beam aggregation for throughput and spectral efficiency improvement.
Simon et al. (2023)	Sub-band allocation and user pairing in dense downlink massive MIMO	User pairing and subband allocation based on minimizing channel matrix condition number (CN) reduction, benchmark resource allocation with rate maximization but high complexity.
Jayasinghe et al. (2024)	Achievable rates analysis for DL and UL in RIS-aided massive MIMO NOMA systems.	A linear minimum mean square error (LMMSE) channel estimation, statistical CSI-based RIS phase-shift optimization.
Nasser et al. (2019)	Interference management and power allocation for sum rate enhancement.	PA-based Interference Alignment and Coordinated Beamforming (PA-IA-CB) scheme for DL-MIMO-NOMA HetNets.
Almasi et al. (2019)	Maximizing sum rate in mmWave NOMA- MIMO.	Investigated beam misalignment and he optimal analog and digital precoders were designed .
Wang et al. (2017)	Maximizing sum rate by integrating NOMA with mmWave MIMO	Using lens antenna arrays, power control algorithms, beam selection for spectral and energy efficiency.
Aghdam et al. (2022)	Minimizing outage probability in mmWave MIMO NOMA system.	Optimal joint power allocation and beamforming in mmWave MIMO-NOMA, random near-random far pairing.
Oubassghir et al. (2024)	Spectral and energy efficiency improvement in NOMA system with massive MIMO and mmWave.	Ergodic capacity and outage probability analysis of NOMA-based mmWave communication with fixed and optimal power allocation.
Yan et al. (2024)	Enhancing capacity and security in vehicular communications.	mmWave-NOMA framework with artificial noise injection, beamforming, and stochastic modeling.
Nasser et al. (2023)	Energy-efficient interference management in mmWave DL-NOMA HetNets.	Data-driven resource block and power allocation to track the network dynamic characteristics to estimate the candidate power vector.
Muhammed et al. (2023)	Energy efficiency improvement for NOMA-HetNets in mmWave with wireless backhaul.	User grouping algorithm, hybrid precoding, joint optimization of precoding, power allocation, and bandwidth partitioning.
Ghafoor et al. (2022)	Energy efficiency maximization in DL-H-NOMA HetNets.	UE clustering, UE admission, UE-BS association, and power allocation, solved using Charnes-Cooper transformation and a two-phase ε-optimal outer approximation algorithm.
Mohamed et al. (2022)	Sum rate maximization in NOMA-HetNets.	Data-driven optimization, resource block allocation, and power allocation considering QoS and SIC.

Figure .8 shows RIS-based NOMA system, $\boldsymbol{h_k}$ is the baseband equivalent channel from the BS to user and $\boldsymbol{r_k}$, $\mathbf{g}$ are the channel from the RIS to user k and from the BS to the RIS, respectively. The base station transmits a superimposed NOMA signal to multiple users. Some users might receive the signal directly, while others receive it via the RIS. Its controller adjusts the reflective elements of the RIS to focus the reflected signal towards the intended users. Then, users decode their signals using SIC, as in traditional NOMA. Overall, RIS is a promising technology that can significantly enhance the performance of NOMA systems by improving signal quality, coverage, and user fairness. This combination has the potential to play a key role in future wireless communication networks.

(Jayasinghe et al., 2024) analyzes the achievable rates for DL and UL communication in RIS -aided massive MIMO systems employing NOMA. A linear minimum mean square error (LMMSE) technique is applied to estimate UL composite channels at the massive MIMO base station, based on user pilots and a predefined RIS phase-shift matrix. To optimize the RIS phase-shifts, a statistical CSI-based approach is adopted, utilizing effective covariance matrices of composite channels corresponding to NOMA clusters with distinct spatial characteristics. By exploiting the slower variation of channel statistics relative to the channel coherence interval, significantly this method reduced pilot overhead and computational complexity. (Tang et al., 2024) investigates the integration of reconfigurable intelligent surfaces (RIS) in UAV-assisted NOMA networks, focusing on reducing overall power consumption. To achieve this, it optimizes key parameters, including UAV positioning, RIS reflection coefficients, transmission power, and decoding order, while ensuring compliance with user rate and UAV spacing constraints. The research breaks down the optimization problem into four sub-problems, which are addressed iteratively using successive convex approximation (SCA), Gaussian randomization, and standard convex optimization techniques. The findings demonstrate a significant reduction in total power consumption, highlighting the benefits of combining RIS with multi-UAV-assisted NOMA networks. (Adam et al., 2020) aims to maximize (EE) in multi-cell multi-carrier NOMA networks while accounting for hardware impairments. The authors introduce a two-stage approach that utilizes the Binary Whale Optimization Algorithm (BWOA) for user association and sub-channel assignment, followed by the Successive Parametric Convex Approximation (SPCA) for PA. Simulation results confirm that the proposed algorithm delivers performance comparable to existing techniques while outperforming benchmarks for both NOMA and OMA systems. (**Tang et al., 2025**) examines a communication system enhanced by RIS and supported by multiple UAVs, incorporating NOMA while accounting for imperfect SIC at user equipment (UE). To maximize system throughput, the research jointly optimizes PA, UAV trajectories, and RIS phase shifts. The mobility of UAVs and UEs makes the optimization problem complex, prompting the development of a two-step approach called Throughput Maximization by Trajectory Design, PA, and Phase Shift Optimization (TM-TDPAPO). The proposed method employs a K-means clustering algorithm for UE grouping, followed by a DDQN technique to tackle the optimization challenge. Simulation results confirm the effectiveness of the presented approach, showing a 57% increase in throughput compared to the conventional DQN algorithm, a 23% improvement over OMA due to imperfect SIC, and a 29% throughput gain when RIS is implemented. These findings underscore the benefits of integrating RIS, UAVs, and NOMA to significantly enhance wireless network performance.

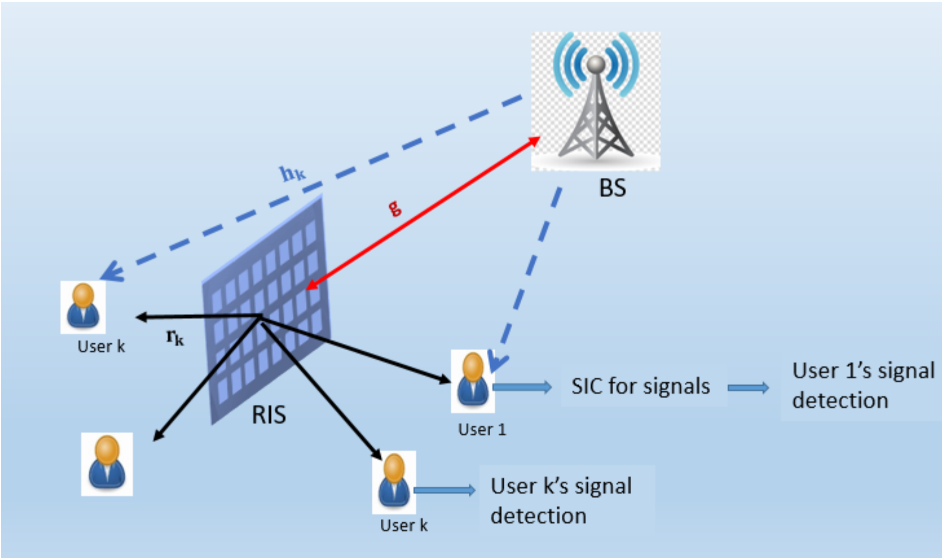

Figure 8. RIS- aided multiuser NOMA system.
Source: (researcher)

2.6. NOMA with ISAC

Integrated Sensing and Communication (ISAC) is an advanced wireless technology that combines wireless communication and environmental sensing into a unified system. Instead of treating sensing and communication as separate functions with dedicated spectrum resources, ISAC enables them to share hardware, spectrum, and signal processing techniques. This integration allows networks to simultaneously transmit data while acquiring information about the surrounding environment, such as object detection, localization, and tracking. This synergy enhances spectral efficiency by reducing spectrum wastage and minimizes power consumption by eliminating the need for separate sensing and communication systems., improves sensing accuracy, optimizes user connectivity, reduces latency, strengthens security, and supports emerging 6G applications. This makes ISAC-NOMA a powerful enabler for future wireless networks, ensuring reliable and high-performance communication in complex and dynamic environments.

Figure.9 explains how NOMA-ISAC works, the BS is the central hub. It transmits a combined signal. This signal isn't just for communication; it's designed for both communications with the users and sensing the environment. Critically, the BS uses NOMA, meaning it superimposes the signals for User 1 and User K (and potentially other users) in the same time/frequency resource block. It does not give them separate slots like in traditional orthogonal multiple access (OMA). The signals for the users are superimposed, and the sensing signal is also incorporated into this superposition. The combined signal travels through the wireless channel towards the users and the targets. The sensing part of the signal hits the various targets in the environment and reflects back towards the BS. This reflected signal carries information about the targets (e.g., their location, distance, velocity). User 1 receives the combined signal. Since User 1 is typically assumed to be closer to the BS (and thus has a stronger signal), it can directly decode its intended communication signal. It treats the signals for User K and the reflected sensing signal as interference. User K also receives the combined signal. However, User K's signal is weaker (as they are usually further from the BS). User K first attempts to detect the reflected sensing signal (Sensing Signal Detection). This is possible because the sensing signal is designed to be decodable, even by User K. After detecting the sensing signal, User K uses SIC. It decodes and removes the sensing signal from the combined received signal. This allows User K to then decode its intended communication signal, considering User 1's signal as interference (communication signal detection). The BS also receives the reflected sensing signals. It processes these signals to extract detailed information about the targets. This information is used for the sensing function of the ISAC system. Hence, the system serves both communication and sensing purposes (Dual functionality). This process allows the NOMA-ISAC system to efficiently use resources for both communication and sensing, potentially improving overall system performance.

(Nasser et al., 2024) introduces multi-armed bandit (MAB)-based strategies to balance communication throughput and radar estimation metrics in NOMA- ISAC systems. The optimization problem is transformed from a multi-objective optimization problem (MOP) into single objective optimization problem (SOP) by a weighted sum strategy, leveraging two MAB variants: the decaying ε-greedy and the upper confidence bound (UCB). These algorithms effectively manage interference by jointly optimizing PA and user-radar target pairing. To accelerate convergence, a multi-MAB framework is introduced, segmenting the network into partitions, each controlled by an independent MAB agent. Additionally, 3 beamforming techniques are proposed: (1) a ZF beamforming (ZF-BF) decoding method, (2) a two-step MAB-based approach that begins with ZF-BF and is refined through an MAB-driven optimization phase, and (3) a beam-sweeping method for imperfect CSI cases. The simulation results confirm that the presented algorithms outperform conventional techniques by an average of 65%, achieving performance within 2% of exhaustive search (ES) while reducing computational complexity by approximately 95%. (Wang et al., 2022) examines a NOMA-assisted ISAC framework, where a dual-purpose BS concurrently serves numerous users via NOMA while utilizing the incorporated signals for target sensing. The research formulates a beamforming optimization problem aimed at maximizing the combined communication throughput and sensing power. In order to overcome this non convex problem, a double-layer penalty-based algorithm is introduced, leveraging successive convex approximation (SCA) techniques. The results indicate that the formulated NOMA-ISAC system outperforms traditional ISAC approaches, particularly in scenarios with high channel correlation in under loaded conditions, and in overloaded network environments. (Nasser et al., 2024), ISAC has emerged as a crucial strategy, extending beyond conventional radar functionality by integrating multiple sensor types to enhance multimodal sensing and communication interactions. With increasing efforts toward ISAC standardization, this article explores the fusion of multiple access schemes with ISAC, with a particular emphasis on NOMA. It comprehensively examines various aspects of ISAC-NOMA, including deployment scenarios, integration challenges, and synergistic opportunities with other wireless communication technologies. The discussion delves into key technical aspects such as interference management, user-target clustering, PA, beamforming, and cooperative communication strategies. To further illustrate these concepts, the article presents two case studies supported by simulation results: joint PA and user-target clustering, as well as simultaneous beam codebook design for both sensing and communication. Additionally, it highlights the potential of ISAC-NOMA in emerging wireless technologies, including cell-free massive MIMO networks, RIS, non-terrestrial networks, and ambient backscatter communication. (Xie et al., 2024) develops a NOMA-enhanced ISAC system to provide low-latency communication services to multiple users while simultaneously sensing an UAV. To support this NOMA-empowered ISAC system effectively, a beamforming-based cross-layer scheduling scheme is introduced, leveraging traffic dynamics at the network layer and CSI at the physical layer. The presented scheme achieves an efficient joint solution for beamforming, PA, and data rate adaptation through a Newton's method-based algorithm and a linear programming formulation. This strategy minimizes the average communication delay while ensuring sensing performance. Additionally, the paper reveals the optimal tradeoff between the average of the transmitted power in the NOMA-empowered ISAC system, and average delay, which is achieved through extensive numerical simulations. Integrating ISAC into a MIMO - HetNets requires a reassessment of network performance, focusing on outage probability and ergodic rates. **(**Parihar et al., 2024**)** presents a new analytical approach to evaluate the transmission in downlink MIMO HetNets. The presented model assumes independent homogeneous Poisson point processes (PPP) to represent the spatial distribution of NOMA-enabled BSs and users. In this setup, the BS in the t^{th} tier utilizes superimposed NOMA signals for target sensing. Active RIS are distributed using homogeneous PPP and are used to reduce blockage for user equipment when the direct link from the BS is unavailable. The study derives approximate and asymptotic expressions for outage probability in two scenarios: one with direct transmission from the BS to a typical blocked user, and another with transmission through active RIS. Additionally, the analysis incorporates the practical scenario of imperfect SIC. The results highlight the advantages of active RIS-NOMA over traditional OMA-HetNets, with notable improvements in outage performance as the count of RIS rises. The study also provides approximations for ergodic rates, system throughput, and beam patterns related to sensing performance. Table 2. Summarizes emerging NOMA with UAV-RIS-ISAC to improve the system performance.

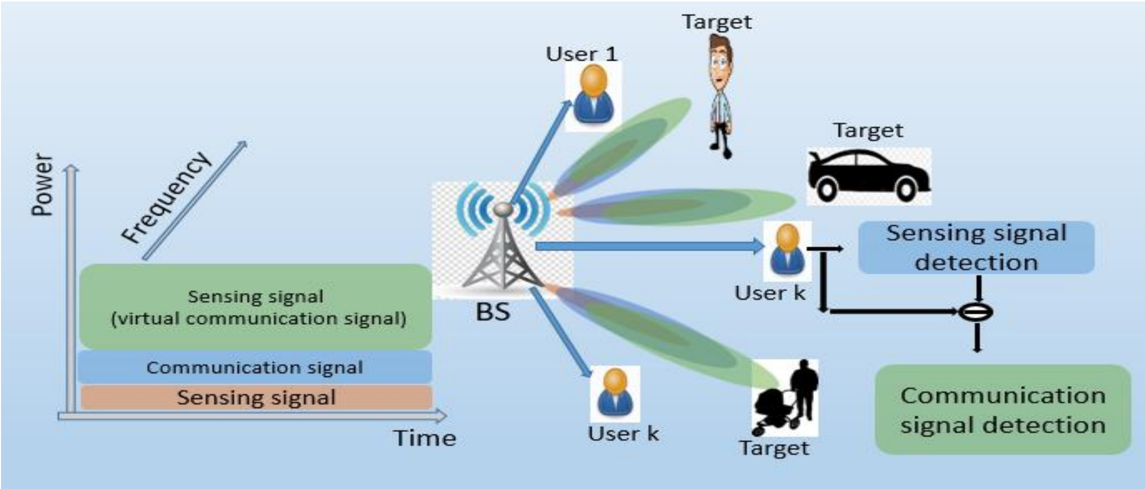

Figure 9. NOMA –ISAC model.
Source: (researcher)

TABLE 2: Summary of integrating NOMA with UAV-RIS-ISAC

Author	Main contribution	Criteria
Tang et al. (2024)	Power consumption reduction in RIS -UAV assisted NOMA.	Optimization of UAV positioning, RIS reflection coefficients, power, and decoding order.
Adam et al. (2020)	Maximizing energy efficiency in multi-cell multi-carrier NOMA systems with hardware impairments.	Utilizing the Binary Whale Optimization Algorithm (BWOA) for user association and subchannel allocation, while employing Successive Parametric Convex Approximation (SPCA) for power allocation.
Tang et al. (2025)	Enhancement of communication system by RIS and supported by multiple UAVs, incorporating NOMA while accounting for imperfect SIC at user equipment (UE).	Joint optimization of power allocation, UAV trajectories, and RIS phase shifts for throughput maximization using K-means clustering and DDQN.
Nasser et al. (2024)	Balancing communication throughput and radar estimation metrics in NOMA- ISAC systems.	MAB-based strategies (decaying ε-greedy, UCB, multi-MAB), joint power allocation and user-target pairing, ZF beamforming and beam sweeping.
Wang et al. (2022)	Maximizing combined throughput and sensing power in NOMA-assisted ISAC.	NOMA-assisted ISAC, beamforming optimization, a double-layer penalty-based algorithm is introduced to overcome the nonconvex problem.
Xie et al. (2024)	NOMA-enhanced ISAC for low-latency communication and UAV sensing.	Beamforming-based cross-layer scheduling, joint beamforming, power allocation, and rate adaptation, Newton's method and linear programming, analysis of power vs. delay tradeoff.
Parihar et al. (2024)	Evaluating the transmission in downlink MIMO HetNets with NOMA and ISAC. The study also provides approximations for ergodic rates, system throughput, and beam patterns related to sensing performance.	Independent homogeneous Poisson point processes (PPP) is assumed to represent the spatial distribution of NOMA-enabled BSs and users.

3. Challenges related with NOMA application

NOMA faces several challenges in its implementation, particularly in power allocation, user clustering and pairing, and successive interference cancellation (SIC) detection. Below is a detailed breakdown of these challenges, including a brief introduction and related works.

3.1. Power allocation

A user's achievable throughput depends on the amount of transmission power assigned to them. Since NOMA relies on power-domain multiplexing, this power allocation also influences the capacity of other users in the system. To maximize date rate in NOMA, an exhaustive search across all possible user pairings with dynamic power allocation would be ideal. However, such a comprehensive search demands significant computational resources, making it highly complex and inefficient. The challenge lies in optimizing power allocation to maximize system throughput, ensure fairness, and meet quality-of-service (QoS) requirements.

- Allocating more power to weak users ensures fairness but may reduce overall system throughput. PA must adapt to rapidly changing channel conditions in real-time.
- Optimal power allocation requires solving non-convex optimization problems, which are computationally intensive.

Different users may have varying QOS requirements, making power allocation more challenging. (Ding et al., 2014) discusses the fundamental principles of PA in NOMA and it has a negative effect on the system performance. (Saito et al., 2013) Introduces the concept of NOMA and highlights the importance of power allocation for achieving superior spectral efficiency. (Dai et al., 2015) Provides a comprehensive overview of power allocation challenges and potential solutions in NOMA systems. To maximize the sum-rate, (Hassan et al., 2014) studies PA problem without QOS guarantees.

3.2. User Clustering and Pairing

User clustering and pairing involve grouping users into clusters and pairing them for resource sharing in NOMA systems. Typically, users with significantly different channel conditions are paired together to maximize the performance gain from power domain multiplexing. The challenge lies in efficiently clustering users while considering their channel conditions, QoS requirements, and computational complexity.

- One of the main obstacles in NOMA is the user pairing process's complexity. To fully benefit from NOMA, including increased system throughput and spectrum efficiency, efficient user pairing is essential. Finding the best user pairings in a dynamic, diverse wireless environment can be computationally demanding, particularly when the count of users rises.
- As the count of users rises up, the complexity of user clustering expands exponentially. Also, user mobility and changing channel conditions require frequent re-clustering. In addition, ensuring that all users, regardless of their channel conditions, are fairly served.

(Al-Imari et al.,2014) discusses user pairing strategies for uplink NOMA and their impact on system performance. (Ding et al., 2017) explores user clustering techniques and their role in improving the efficiency of NOMA systems. (Choi et al., 2017) proposes a user pai ring algorithm for downlink NOMA systems and evaluates its performance.

3.3. SIC Detection

Successive Interference Cancellation (SIC) is a key technology in NOMA systems that enables users to decode their signals by canceling interference from other users. In SIC, users decode and subtract stronger signals before decoding their own signal. The challenge lies in ensuring accurate SIC detection, especially in the presence of defective CSI and HWI.

- Errors in decoding stronger signals can propagate and degrade the performance of weaker signals.
- SIC requires significant computational resources, mainly in systems with higher capacity, which increases the complexity.
- Inaccurate channel estimation can lead to imperfect interference cancellation. SIC introduces additional processing delay, which may not be suitable for latency-sensitive applications.

(Ding et al., 2015) analyzes the impact of SIC on NOMA performance and proposes techniques to mitigate error propagation. (Dai et al., 2015) discusses the challenges of SIC in NOMA systems and potential solutions to improve its accuracy. Table 3, summarizes NOMA challenges.

4. Future Direction Discussion

As the demand for high-speed, ultra-reliable, and energy-efficient wireless communication continues to grow, NOMA has emerged as a key technology for enhancing spectral efficiency and enabling massive connectivity. When combined with advanced technologies such as massive MIMO, mmWave, HetNets, UAV, RIS, and ISAC, NOMA can further improve resource utilization and boost overall network performance. Despite its advantages, NOMA still encounters several technical challenges, including interference management, optimal power allocation, hardware complexity, and real-time deployment in large-scale networks. Overcoming these challenges is crucial to ensuring scalability, adaptability, and seamless integration into future wireless systems, particularly in the era of 6G and beyond.

Table 3: Summary of NOMA-challenges

Challenges	Authors	Main contribution
Power Allocation	Ding et al. (2014)	Principles of power allocation.
	Saito et al. (2013)	Importance for spectral efficiency
	Dai et al. (2015)	Challenges and solutions
	Hassan et al. (2014)	Sum-rate maximization without QoS.
User Clustering/Pairing	Al-Imari et al. (2014)	Uplink NOMA pairing strategies.
	Ding et al. (2017)	Clustering techniques
	Choi et al. (2017)	Downlink pairing algorithm
SIC Detection	Ding et al. (2015)	Impact on NOMA, error mitigation.
	Dai et al. (2015)	Challenges and solutions.

The following sections will explore some of the key future directions that will drive the continued advancement and widespread adoption of NOMA.

4.1. NOMA with Massive MIMO

- The convergence of NOMA and massive MIMO with 6G technologies, such as intelligent reflecting surfaces (IRS), terahertz (THz) communication, and quantum communications, is a promising direction. These integrations aim to further enhance spectral efficiency, reduce latency, and provide ultra-reliable low-latency communication (URLLC).

- Investigating hybrid analog-digital beamforming techniques tailored for NOMA in massive MIMO systems can improve energy and spectral efficiency, especially in terahertz frequency bands and millimeter-wave.

- Enhancing physical layer security for NOMA aided massive MIMO, especially in dense environments, using advanced encryption, authentication, and jamming techniques.

4.2. NOMA with mm Wave communication

- mmWave relies on highly directional beamforming due to severe path loss, requiring precise alignment between transmitters and receivers. focusing on hybrid analog-digital precoding techniques to optimize beam alignment and interference mitigation in NOMA-mmWave systems should be considered. High-frequency transmission in mmWave consumes significant power, making energy efficiency a key concern. Hence, future research should focus on low-power hybrid beamforming, energy-efficient hardware, and optimized NOMA transmission schemes to reduce power consumption. Green communication solutions, such as energy harvesting and intelligent sleep modes, should be explored.

4.3. NOMA with RIS

- The trend aims to enhance RIS-assisted NOMA beamforming through sophisticated algorithms, AI-powered phase shift optimization, and dynamic resource allocation techniques. Effective user clustering and optimized power distribution are crucial for improving spectral efficiency while minimizing interference. Moreover, overcoming the challenge of imperfect channel state information (CSI) by utilizing deep learning-based prediction models and robust channel estimation methods will be vital for ensuring stable system performance.

- In addition to theoretical advancements, addressing practical implementation challenges such as hardware limitations, energy efficiency, and cost-effective deployment is essential. The integration of RIS-aided NOMA with Massive MIMO, Terahertz (THz) communication, and upcoming 6G technologies will significantly improve connectivity, supporting ultra-reliable low-latency communication (URLLC). Furthermore, security challenges, including RIS-enhanced physical layer protection and secure beamforming, must be addressed with innovative solutions. Ultimately, RIS-NOMA stands out as a promising approach for future wireless networks, delivering enhanced spectral efficiency, broader coverage, and improved energy efficiency in next-generation communication systems**.**

4.4. NOMA with ISAC

- The advancement of NOMA for ISAC will center on refining resource allocation and mitigating interference to ensure the seamless integration of sensing and communication. Leveraging advanced signal processing and machine learning techniques will be crucial in enhancing spectral efficiency while minimizing interference between these two functions. Additionally, the development of beamforming and power control strategies will be essential to maintaining both high data transmission rates and accurate target detection. Overcoming challenges related to hardware constraints, imperfect CSI, and real-time optimization in dynamic environments will be key to improving overall system efficiency.

- Beyond theoretical improvements, addressing practical concerns such as hardware implementation, energy efficiency, and regulatory frameworks will be necessary for real-world adoption. The convergence of NOMA-ISAC with cutting-edge technologies like terahertz (THz) communication**,** RIS, and 6G networks will support URLLC and high-precision sensing applications.

5. Conclusion

This survey paper explores the integration of Non-Orthogonal Multiple Access (NOMA) with advanced wireless technologies, including massive MIMO, millimeter-wave (mmWave) communication, UAV-assisted networks, Reconfigurable Intelligent Surfaces (RIS), and Integrated Sensing and Communication (ISAC). By leveraging the advantages of each technology, we present the fundamental system models that enhance spectral and energy efficiency, and support massive connectivity. Also, we address key challenges in NOMA, such as power allocation, user pairing/clustering, and Successive Interference Cancellation (SIC) detection, which are critical for enabling next-generation wireless networks. Additionally, we provide an in-depth discussion on the future directions of integrating NOMA with each of these technologies, highlighting potential advancements in resource optimization, reduce latency, improve connectivity, security, and real-time implementation. Finally, the synergy between NOMA and these emerging technologies is expected to play a pivotal role in meeting the ever-growing demands for higher data rates, enhanced spectrum utilization, and energy-efficient communication systems. By addressing both the challenges and future research directions, this paper contributes by compiling and analyzing the latest advancements for the evolution of 6G and beyond.

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