A Survey of Non-Orthogonal Multiple Access for Internet of Things and Future Wireless Networks

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Abstract. Non-orthogonal multiple access (NOMA) is an effective multiple access technique for future generations of wireless networks. It has large spectral efficiency, enabling high connectivity, which is essential for Internet of Things (IoT) applications. IoT applications initiate an industrial and user revolution era with massive connected devices. The paper discusses various NOMA schemes for IoT applications and their implementation for massive IoT networks. It also describes the current limitations of NOMA for IoT, including security, successive interference cancellation (SIC), power allocation, and channel estimation. Various deep learning applications along with a comprehensive study of several promising technologies for massive wireless connectivity, millimeter-wave (mm-Wave), massive multiple-input multiple-output (mMIMO), and unmanned aerial vehicles (UAV) communication are also illustrated based on NOMA-IoT applications.

Keywords: NOMA, IoT, Massive MIMO, mm-Wave communication

1 Introduction

Network traffic has considerably raised because of the quick expansion of mobile and smart device applications. Future communication systems can eventually be improved by utilizing multiple access approaches to achieve maximum data speeds to the wireless network and the Internet of Things (IoT) applications. The appropriate multiple access scheme is an essential consideration in designing and operating cellular communication networks to ensure efficient use of limited bandwidth resources and provide reliable communication services to many users [1]-[2]. Non-orthogonal multiple access (NOMA) uses advanced signal processing techniques to separate and decode the overlapping signals transmitted by various devices. It allows for effective use of spectrum resources and increased capacity, as various devices can communicate simultaneously [3]. Different multiple access schemes are illustrated in Fig 1.

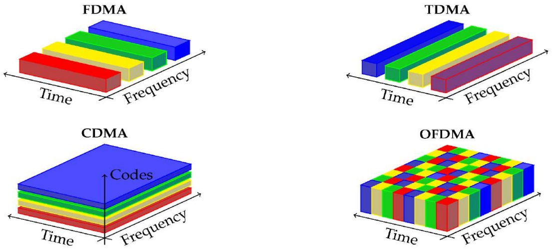

Fig. 1. Graphical representation of FDMA, TDMA, CDMA, OFDMA.

The various future generation-based IoT applications are shown in Fig 2. NOMA-IoT is a multiple-access scheme that enables various devices to have the same frequency, time, or code resources for communication. Different wireless technologies are being studied to provide such extensive communication. It is advantageous in IoT networks where many devices with varying communication requirements must communicate with a central base station. By allowing devices to transmit non-orthogonally, NOMA-IoT can improve system capacity, reduce latency, and enhance energy efficiency, making it a promising technique for future-generation IoT networks. Overall, NOMA-IoT is an emerging technology that has the potential to improve IoT networks' performance and efficiency, and it is a field of active study and development in the field of IoT communication based on future-generation wireless networks. Because future IoT applications will involve a vast number of different types of connected devices, it is critical to create numerous technologies to facilitate their communication. Regarding cover-

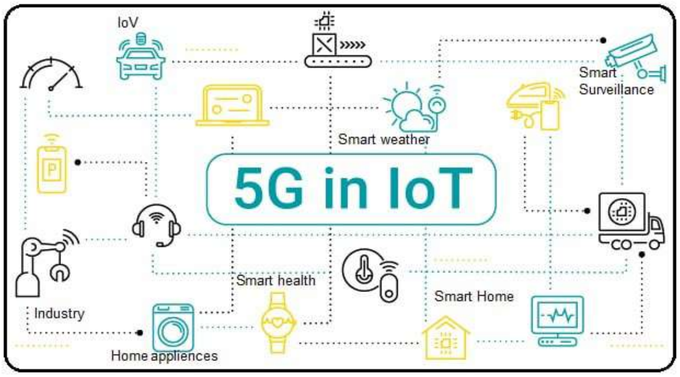

Fig. 2. 5G IoT applications.

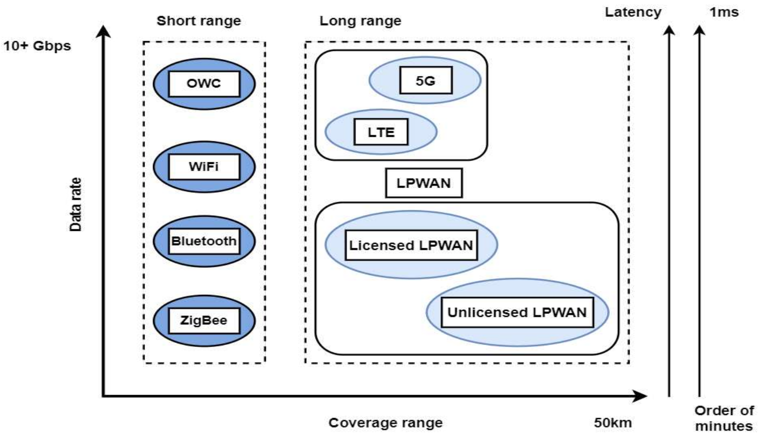

Fig. 3. The data rate, range, and latency of various IoT connection technologies.

age range and latency, the wireless connectivity technologies classify short-range and long-range technologies as represented in Fig 3 [4].

The remaining sections of the paper are organized as follows. The NOMA network overview is illustrated in section 2. Section 3 describes IoT with NOMA. Section 4 includes the application of NOMA for massive cellular IoT. Section 5 and Section 6 analyze the novel technologies for massive wireless connectivity and conclude the paper, respectively.

2 NOMA OVERVIEW

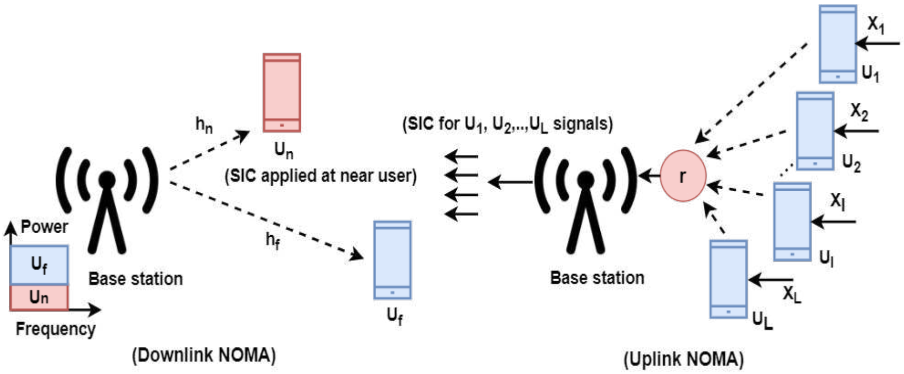

Fig. 4. NOMA networks.

NOMA is an effective multiple-access scheme for future wireless communication technologies. It has already been investigated for integration into the future generation of wireless communication systems. The NOMA differs from traditional orthogonal multiple access (OMA) schemes by enabling users to use the same frequency and time resources using superposition coding and SIC techniques. This gives more efficient spectrum utilization, higher capacity, and better reliability than OMA. NOMA has the potential to support massive connectivity for various emerging applications such as Machine-to-Machine (M2M) communications, the IoTs, and ultra-reliable low-latency communication (URLLC). Fig 4 illustrates the principle of the downlink NOMA and uplink NOMA networks [5]-[6].

2.1 Downlink NOMA

Downlink NOMA is used in wireless communication systems where multiple users utilize the same frequency and time resources to receive data from a single base station. Each user is assigned a specific power level in this technique. The signal transmitted from the base station is superimposed with the signals meant for all the users with their power coefficients. According to their channel conditions, users' power coefficients are allocated. U_n is the near user and U_f is the far user. h_n is the channel gain of the near user and h_f is the channel gain of the far user. As $|h_n| > |h_f|$, consider downlink transmission from the base station and the maximum transmission power for the base station is P. Here, $\alpha_n < \alpha_f$ (α_n: near user's power coefficient; α_f: far user's power coefficient) and $\alpha_n + \alpha_f = 1$. X_n and X_f are the transmitted signals at the base station for U_n and U_f, respectively. It allocates higher power to the far user and low power to the near user. The received signal at U_n is given by

$$Y_n = \sqrt{P}(\sqrt{\alpha_n}X_n + \sqrt{\alpha_f}X_f)h_n + W_n \tag{1}$$

The received signal at U_f is given by

$$Y_f = \sqrt{P}(\sqrt{\alpha_f}X_f + \sqrt{\alpha_n}X_n)h_f + W_f \tag{2}$$

W_n and W_f are the AWGN noise at U_n and U_f, respectively. Here, the far user's signal decodes directly by assuming other signals as noise due to high transmission power. The near user performs SIC, decodes far user signals, and cancels it from the received signal to obtain its original signals.

2.2 Uplink NOMA

The users transmit signals to the base station in an uplink NOMA network. The far user's signal is first decoded and taken away from the superimposed signal accessed at the base station using SIC. Uplink NOMA is less complicated to apply than downlink NOMA and has higher spectral efficiency. SIC uses less energy since it is performed at the base station. In an uplink NOMA network, many users send signals to the same base station in the same resource block with varying power levels.

2.3 Cooperative NOMA

Cooperative NOMA can improve user communication dependability with different channel circumstances [7]. The transmission within the base station and users is retained with one or more relays. The near users can operate as relays, sending the previous data to the far users. The far users have two possibilities. They can either detect and decode their data directly from the base station or rely on the signal of nearby users. It can increase the system's capacity. Relaying can also extend the base station's coverage area. It helps to improve the network's overall performance by reducing interference and improving the quality of the received signal.

3 IoT WITH NOMA

Wireless technologies have successfully supported numerous IoT applications. There are still outstanding concerns and challenges in meeting the expected demands of future IoT applications with huge linked items [8]-[9]. Device mobility is a crucial component of 5G IoT networks. Internet of Vehicles (IoV) and unmanned-aircraft vehicle systems (UAVs) are two examples of 5G IoT applications for intelligent traffic and smart cities [10]-[12]. Authentication requests will be frequent if IoT devices move quickly and switch between multiple base stations to provide a rapid and efficient solution. As a result, excessive authentication handover may cause authentication delays that exceed the latency tolerance of future generation network services [13]. NOMA is a potential strategy for accommodating the massive number of IoT users expected in future communication. It has also been studied to provide grant-free transmissions, particularly in massive machine-type communications (mMTC), where devices may communicate data whenever they need it without scheduling requests because of its vast connection potential. Using grant-free communication, devices can transmit data whenever needed without going through random access. Grant-free-based transmission utilizing NOMA is a possible option. The multiple access techniques in NOMA determine the overloaded effectiveness and complexity of the multi-user detection receiver at the base station. It can implement interleaving, linear spreading, multi-dimensional modulation, and scrambling at the transmitter [14]-[15]. According to recent studies, deep learning-based precoding is better suited for different applications in terms of latency and complexity [16]-[17]. Deep reinforcement learning has many applications in IoT, and this reinforcement learning approach produces excellent performance [18]. Integrating IoT with NOMA can improve the performance of IoT systems in several ways. First, NOMA can increase the number of devices accessing the network, enabling more devices to be connected to the network simultaneously. Second, it can enhance the spectral efficiency of the network, allowing more data to be transmitted within the same frequency band. It can also help IoT devices transmit and receive data more quickly and efficiently, improving system performance. One potential application of IoT with NOMA is in smart cities. By using NOMA, more devices can be connected to the network, allowing for better data

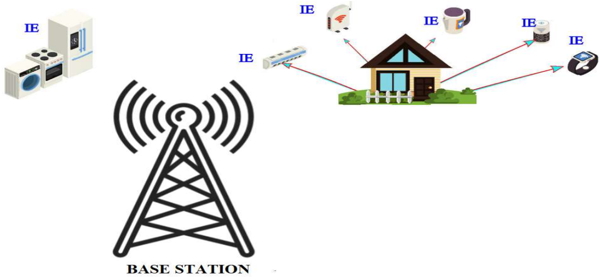

Fig. 5. NOMA- IoT network

collection and analysis. It can lead to more efficient use of resources, reduced congestion, and improved safety. Integrating IoT with NOMA can enhance the performance and efficiency of IoT systems in various applications.

Fig 5 shows a multi-carrier NOMA-based IoT network where the BS supports IoT equipment (IEs). The base station is frequently accessed to have comprehensive channel state information (CSI) for all related IEs. For both base stations and IEs, it assumes single antennas for modeling. It may accommodate numerous IEs at the same time by utilizing NOMA's power multiplexing. It allows IEs with better channel conditions to identify, decode, and eliminate interference from IEs with poorer channel conditions. Here, Table 1 describes a summary of massive wireless connectivity for future wireless networks.

4 NOMA FOR MASSIVE CELLULAR IoT

The NOMA for machine-to-machine communication devices can access the network without using the random-access mechanism. The devices instead combine the random access and data transmission functionalities and deliver their information over several randomly selected sub-bands. It is necessary to lower overhead, which is essential for many machine-to-machine systems [19]. NOMA can be used in Massive Cellular IoT to enhance the capacity and efficiency of the system. By using NOMA in Massive Cellular IoT, multiple devices can be supported in the same time and frequency resources without requiring additional resources or causing interference. It also allows for efficient use of the available spectrum and can help to support the massive number of devices cost-effectively. Furthermore, NOMA can be integrated with other techniques, such as beamforming and interference management, to improve the system's performance further. Overall, NOMA for Massive Cellular IoT can provide a promising solution for supporting the growing demand for low-power and low-cost IoT devices.

Table 1. Summary of massive wireless connectivity

Type	Characteristics
NOMA [3]	– Improved capacity, spectral efficiency, and fairness. – Interference occurs, complexity reduction by hybrid automatic repeat request and multiple access adaptation in retransmission.
Cooperative NOMA [7]	– Enhanced coverage and improved energy efficiency with user pairing scheme. – Complexity and security issues.
mMIMO [28]	– High capacity and spectral efficiency. – High energy consumption (more no. of antennas) and signal processing complexity.
mmWave [8]	– High bandwidth and high security. – Low interference. – Limited range and high power consumption.
Machine learning [29]	– Optimized network operations and enhanced spectrum efficiency. – Increase the complexity of the system for decision process.
VLC [30]	– High security with no interference with radio signals. – Limited range with line-of-sight communications.
UAV [11]	– Flexible, mobile, and cost-effective way to provide wireless communication services. – Energy efficiency and ground station connection issues are quite challenging.

4.1 NOMA's Potentials for Massive Cellular IoT

NOMA enables non-orthogonal resource sharing between multiple devices, enabling massive cellular IoT. It reduces resource allocation and scheduling overhead and improves network spectral efficiency. It can enable massive connectivity with IoT devices. By permitting multiple devices to use the same resource, NOMA can increase the number of devices the network can support without additional spectrum. It can lead to more efficient spectrum use, a valuable resource in cellular networks. However, some challenges are associated with NOMA for massive cellular IoT. Designing a receiver that separates signals from multiple users with varying power levels is challenging. It is also essential to have an accurate CSI to allocate power levels appropriately.

4.2 Massive NOMA for Massive Cellular IoT: Practical Considerations

The Massive NOMA technique can enable massive connectivity in cellular IoT networks. The device allows multiple IoT devices to share a resource by allocating different power levels according to channel conditions. However, various practical issues must be considered while implementing massive NOMA for cellular IoT. The receiver design for massive NOMA is more complex than that for traditional orthogonal multiple access. It requires signal processing techniques to separate the signals from various devices with different power levels. It can increase the receiver's complexity, leading to higher power consumption and cost. Accurate CSI is crucial for adequately allocating power levels in massive NOMA. Interference management is critical in massive NOMA, as multiple devices share the same resource. Interference can arise from both intra-cell and inter-cell interference. Techniques such as interference alignment and cancellation can mitigate interference but also increase the system's complexity. Proper power control is essential in massive NOMA to ensure optimal power is allocated to each device. Power control algorithms can adjust the power levels dynamically according to the channel conditions. However, designing such algorithms can be challenging, especially in the presence of interference. A viable alternative approach to enhance the energy efficiency (EE) of IoT networks and increase the connectivity of radio-frequency (RF)- energy harvesting (EH) technology [20]-[21]. Simultaneous wireless information and power transmission (SWIPT) and the wireless powered communication network (WPCN) are two popular RF-EH technologies for short-distance and long-distance communications [22] -[23]. IoT devices need to use particularly advanced cryptography to maintain reasonable security. Because of the broadcast nature of wireless communications, establishing communication security is essential. Physical security is a robust application for secure communications. These security measures take advantage of numerous physical characteristics of communication routes among communicative entities to facilitate fast data transfer. The most effective techniques in this field are beam-forming methods, transmit antenna selection, and relay-based physical security systems. These methods have been discussed and are typically applied to NOMA systems [24]-[25].

5 NOVEL TECHNOLOGIES FOR MASSIVE WIRELESS CONNECTIVITY

Although specific IoT applications have been supported by the wireless IoT technologies currently in use, there are still challenges to satisfy the demands of future IoT applications with massive connected devices [26]. Managing enormous connections from IoT devices with sporadic characteristics and modest transmission payloads is one of the significant challenges. Additionally, only a few wireless resources are allotted for IoT connectivity. These resources are used in an orthogonal manner, leading to a shortage of wireless resources and ineffective wireless resource utilization for massive connectivity. To solve these problems, researchers are still creating new technologies to enhance existing methods while retaining their better characteristics.

5.1 Compressive Sensing (CS) based connectivity

Compressive Sensing (CS) is a signal processing technique that allows the recovery of a sparse or compressible signal from a small number of linear measurements [27]. This technique has been widely used in various applications, including IoT systems. CS-based connectivity on NOMA-IoT refers to compressive sensing techniques to enable reliable communication between IoT devices in NOMA networks. In NOMA-based IoT networks, the CS technique can be used to estimate the channel coefficients between IoT devices and the base station, which can optimize the power allocation and user scheduling in NOMA. IoT devices use compressed measurements to estimate the CSI and jointly detect the transmitted signals. CS-based connectivity on NOMA-IoT minimizes the energy consumption of IoT devices and extends the network capacity and reliability. It improves the system's spectral efficiency, allowing more IoT devices to be connected to the network.

5.2 Massive multiple input multiple outputs (mMIMO)-based connectivity

Massive multiple input multiple outputs (mMIMO) is a wireless communication technology that uses many antennas at the base station to serve numerous users simultaneously [28]. mMIMO-based connectivity in NOMA-IoT refers to using mMIMO technology to enable reliable and energy-efficient communication between IoT devices in NOMA networks. In this approach, the base station uses many antennas to simultaneously serve multiple IoT devices using NOMA's power domain multiplexing feature. The base station can distinguish between the signals of different IoT devices by exploiting the channel characteristics of the wireless medium. mMIMO-based connectivity in NOMA-IoT can support many IoT devices with varying traffic requirements, improving the system's scalability and providing high spectral and energy efficiency, reducing the cost of deploying and operating the system.

5.3 Machine learning assisted connectivity

Machine learning (ML)-assisted connectivity in NOMA-IoT refers to using ML techniques to improve the connectivity between IoT devices in NOMA networks [29]. This approach uses ML algorithms to learn the channel characteristics and predict the CSI for each IoT device in the network. The predicted CSI can be used to improve NOMA's power allocation and resource allocation, which can enhance the system's overall connectivity and energy efficiency. It can adapt to changing wireless environments and provide dynamic optimization of the system parameters, improving its performance and reliability and making it easier to implement in resource-constrained IoT devices.

5.4 Millimeter-wave (mmWave)

Millimeter-wave (mmWave) on NOMA-IoT refers to using mmWave communication technology in NOMA networks to enable high-speed and reliable communication between IoT devices. In this approach, mmWave technology transmits data between the base station and the IoT devices, while NOMA supports multiple IoT devices on the same channel. The system achieves low latency and high data rates using mmWave technology, which is essential for many IoT applications. It offers high data rates and minimal latency for many IoT applications, including industrial automation, remote surgery, and virtual reality. Its support for several IoT devices with various traffic demands enhances system performance.

5.5 Visible light communication (VLC)

Visible Light Communication (VLC) uses light to transmit data in a wireless channel [30]. VLC on NOMA-IoT provides high data rates and low power consumption, essential for many IoT applications, including indoor positioning, smart lighting, and indoor navigation. Secondly, it supports a vast number of IoT devices with various traffic requirements, which improves the effectiveness of the system. Finally, it provides secure communication, as VLC signals cannot pass through opaque materials, enhancing the system's security.

5.6 Unmanned aerial vehicles (UAV) communications

Unmanned aerial vehicles (UAV) communications on NOMA-IoT refers to using NOMA technology in UAV networks to support communication between UAVs and ground stations. NOMA can be used to support multiple UAVs on the same channel, which improves the efficiency and scalability of the system. It provides enhanced spectral efficiency, essential for UAV networks with limited available spectrum. Secondly, it supports a large number of UAVs with different traffic requirements, which improves the scalability of the system. Finally, it can enhance the reliability of communication between UAVs and ground stations, which is essential for many UAV applications, including search and rescue, disaster response, and environmental monitoring.

6 Conclusion

NOMA is one of the most proper techniques for large IoT networks because of the faster speed and improved spectral efficiency over conventional techniques. This paper discusses the basic concept of NOMA with IoT and the advantages and drawbacks of using NOMA-IoT with several practical considerations. Implementing SIC with higher complexity and error-free devices with limited processing capabilities is also a crucial problem. Furthermore, to achieve better performance, we have discussed novel technologies for massive wireless connectivity, mmWave, UAV, and mMIMO communications with NOMA-IoT applications. As for future research directions, it can take advantage of the deep learning-based IoT methods for optimal power allocation for users, channel state estimation, and detection of the symbols in the receiver.

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