Multiple Access Schemes for 6G Enabled NTN-Assisted IoT Technologies: Recent Developments, Prospects and Challenges

A. F. M. Shahen Shah, Muhammet Ali Karabulut and Khaled Rabie

Abstract

The transition from 5G to 6G will result in an explosion of Internet of Things (IoT) devices that provide pervasive and constant connection across all spheres of human activities. In this regard, non-terrestrial networks (NTNs) will play a crucial role in supporting and supplementing terrestrial systems in order to cope with such a vast number of IoT devices and to fulfill the massive capacity needs of the most sophisticated of them. This study investigates the implication of several multiple access techniques for 6G enabled NTN-assisted IoT technologies. First, general architecture of NTN, NTN-assisted IoT technologies, and key features and challenges of NTNs are presented. Then, different types of multiple access schemes are discussed and compared in the context of NTN-assisted IoT systems. Simulation results are presented and important performance parameters such as energy efficiency and spectrum efficiency are examined for the discussed multiple access schemes. Furthermore, challenges and future research directions are discussed.

Introduction

The sixth generation (6G) system is the next step in the evolution of wireless communication technologies, with the goal of delivering faster speeds, lower latencies, and higher capacities than previous generations of communications systems. To actualize this promise, the 6G network could incorporate a communications infrastructure that can extend beyond the ground into space and other non-terrestrial realms. Non-terrestrial networks (NTN) come into play here. NTN is a technology that uses non-terrestrial resources such as satellites, drones, and other aerial vehicles in space to establish communication networks. This expands 6G coverage, allowing access to more geographical areas. Furthermore, NTN supports Internet of Things (IoT) applications, allowing billions of devices to communicate and exchange data more easily. IoT allows objects to connect to the internet and share data via sensors, gadgets, and other physical assets. 6G and NTN maximize the possibilities of IoT applications by allowing devices to be integrated over considerably larger areas and with stronger connectivity. As a result, 6G, NTN, and IoT complement one another, forming an integrated communication ecosystem capable of meeting the future's high-speed, wide-coverage, and low-latency requirements [1-4].

As NTN spreads its communications infrastructure to more geographically and geographically remote places, it has significant potential to support IoT application. NTN-powered IoT connects and exchanges data in various communication networks beyond the planet, allowing billions of items, devices, and sensors to connect and exchange data. This has the potential to transform remote monitoring, environmental monitoring, agriculture, transportation, and many other industries. It is also useful in critical sectors such as emergency communications and disaster management. NTN and NTN-supported IoT lay the groundwork for a more connected and intelligent world of the future by providing communications and data infrastructure for more connection and interaction in the universe [2-6].

This article differs from other studies in the literature by discussing multiple access schemes for NTN-assisted IoT technologies supported by 6G. The article not only focuses on existing communication technologies, but also explores how these technologies can be integrated into NTN systems and the potential impacts of this integration in IoT applications. It also contributes to the field by addressing the future outlook of IoT powered by 6G technologies and the potential challenges it may face. This article aims to make a significant contribution to the development of multiple access schemes for 6G and NTN-supported IoT technologies by providing an innovative perspective beyond previous studies. The following is a summary of this article's contributions to the literature.

- General architecture of NTN, NTN-assisted IoT technologies, and key features and challenges of NTNs are presented.
- Different types of multiple access schemes for 6G enabled NTN-assisted IoT technologies are discussed.
- This article covers the latest discoveries and advancements in the field of multiple access technology, covering the latest developments for 6G and NTN-enabled IoT technologies.

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- Simulation results are presented, along with a comparison of various access techniques in the context of NTN-enabled IoT system.
- A comprehensive discussion on the future potential of 6G and NTN-enabled IoT systems and the challenges these technologies may face.

The rest of the article is organized as follows. The NTN is stated. We present the multiple access schemes. Simulation results are given. We present future research and direction. Concluding remarks are then given.

Non-Terrestrial Network

NTN's contribution to future communications infrastructure is founded on a number of major benefits. First, space and aerial platforms provide wider coverage than ground-based platforms. Second, NTNs can be deployed faster than ground-based infrastructure and provide faster responses to important applications such as emergency communications. Third, NTNs can easily manage huge data streams and deliver high bandwidths, making it excellent for 4K video streaming, virtual reality experiences, and other data-intensive workloads [2–6]. Figure 1 shows an NTN architecture. Figure 1 exemplifies a multi-layered approach showing the integration of various communication technologies such as satellite, unmanned aerial vehicles (UAVs), aircraft, balloon. NTN may contain a combination of these elements individually or together. Different types of user equipment are used in NTN, including IoT devices, cellular devices, and wireless sensors, each with different Quality of Service (QoS) requirements. Terrestrial ground station connects with terrestrial networks and manages communication with ground-based IoT devices. Base station controllers control and coordinate communication between the terrestrial ground station and IoT devices. Low Earth Orbit (LEO) satellites, UAVs, and High-Altitude Platform Stations (HAPS) are typically closer to the Earth's surface than Geostationary Earth Orbit (GEO) satellites. GEO satellites can provide wide-area coverage, while LEO satellites or UAVs may offer additional capacity or targeted coverage for specific applications. Combining different types of satellites or platforms can enhance the overall resilience and reliability of a communication system. If one component experiences issues, others may still provide connectivity, improving the overall robustness of the network.

Harmonization of the spectrum is required to guarantee seamless communication between NTN and TN. Spectrum harmonization prevents disputes and interference between networks that use the same frequency. The 3GPP RAN4 group is critical to coordinating these spectrum harmonization activities. Users should be able to smoothly transition between NTN and TN. Spectrum harmonization makes these transitions easier. Spectrum harmonization guarantees that current norms and legal restrictions are followed. This assures that NTN and TN function in conformity with the law. Organizations such as the 3GPP RAN4 group take on the role of developing and coordinating standards in this area, allowing for more efficient and smoother NTN-TN integration. IMT-2030 establishes a worldwide framework and specifications for future mobile communications technology. The

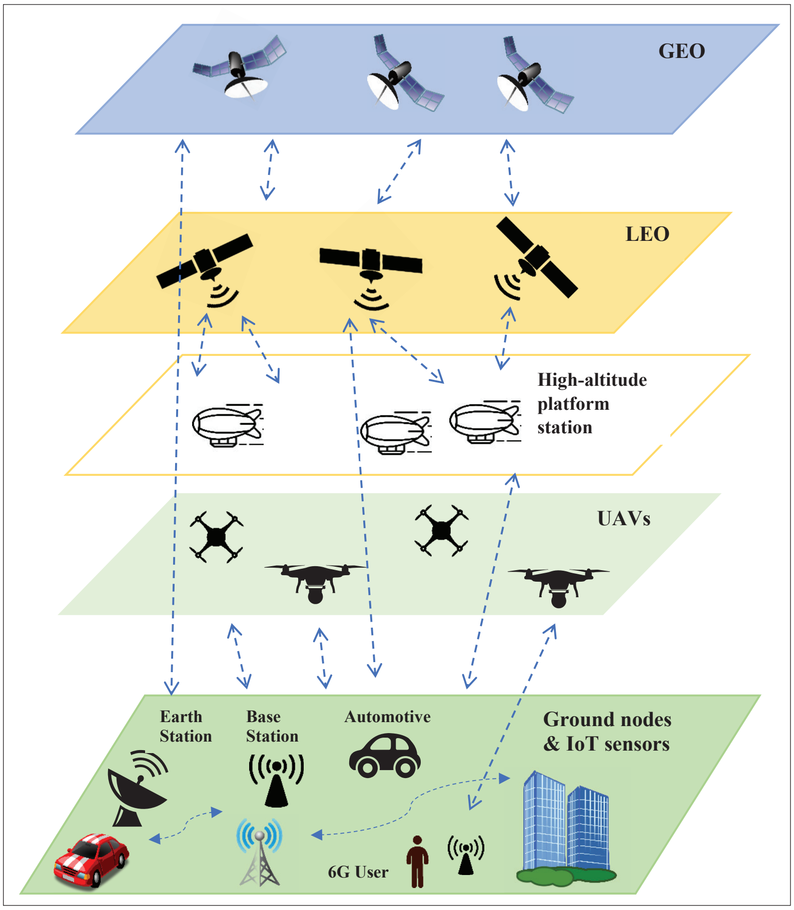

FIGURE 1. Network architecture for NTN.

compatibility of NTN IoT and IMT-2030 standards allows future NTN networks to accommodate IoT applications more effectively.

NTN-Assisted IoT Technologies

NTNs are a technology idea that uses non-terrestrial resources such as space and air platforms to develop communications infrastructure as an alternative to standard ground-based communication networks. The IoT is a technology that enables devices to connect to the internet and exchange data. When combined, these two technologies have enormous potential in a wide range of applications.

- *IoT Devices*: Sensors, data gathering devices, or interactive objects located in diverse objects are examples of IoT devices that constitute the foundation of NTN-supported IoT technologies. These gadgets detect physical characteristics in their surroundings and collect and process the information.
- *Platforms for Data Processing and Analysis*: Data from IoT devices is transported to platforms for data processing and analysis. These platforms analyze massive amounts of data, turning it into relevant information and actionable data. IoT applications are built on data processing and analysis, and machine learning (ML) and artificial intelligence (AI) techniques are widely used at this point.
- *NTN Infrastructure*: The NTN infrastructure is used to transport data from IoT devices. Satellite networks, drones, and balloons are

FDMA was used in the 1G system, where the available spectrum was divided into single-user, non-overlapping frequency bands.

examples of NTN sources that enable data connection between IoT devices in remote places and central servers. NTN broadens IoT coverage by expanding connectivity infrastructure beyond the earth's surface.

Key Features and Challenges of NTNs

NTN technologies have numerous advantages, including broad coverage, fast data speeds, and low latency.

- *Extensive Coverage*: NTNs provide extensive coverage by utilizing non-terrestrial resources such as satellite networks in orbit, drones, balloons, and other aerial platforms. As a result, they offer access to a wide range of geographical places, including distant and rural areas.
- *High Data Rates*: Because of their high bandwidths and communication rates, NTNs can efficiently handle huge data streams. This is critical for high-definition video feeds, virtual reality (VR), and augmented reality (AR).
- *Low Communication Latencies*: Low communication latency is essential for NTN networks to function well and allow real-time applications. Research and technological development are critical for making progress and overcoming this obstacle. 6G technologies, in particular, and the IMT-2030 framework, are heavily supporting research and standardization efforts to produce reduced communication latency.
- *Emergency Communications*: NTNs are essential for disaster management and emergency communications. NTNs offer rapid and reliable communications when traditional infrastructures are destroyed or have reached their capacity.
- *Multiple Access Techniques*: NTNs can employ a variety of multiple access techniques to allow numerous devices to connect to the network at the same time.

One the other hand, there are some challenges that face NTNs and this includes high costs, regulations, security concerns and technological compatibility. Therefore, it is important to take these challenges into account and explore solutions for the successful implementation of NTNs.

- *High Costs*: Non-terrestrial resources such as satellite networks and airborne platforms may necessitate costly infrastructure investments. This may raise initial expenses.
- *Regulation and Licensing*: Space and aerial platforms are often subject to stringent regulatory and licensing requirements. This can make NTN implementation harder.
- *Technological Compatibility*: Technological compatibility and integration of various NTN components (satellites, drones, ground stations, etc.) can be a complex engineering task.
- *Spectrum Restrictions*: The use of NTNs may be limited due to frequency range restrictions, spectrum constraints, and limits.

Multiple Access Schemes

Multiple access techniques are critical for 6G enabled NTN-assisted IoT Technologies since they must enable several devices to interact at the same time. These techniques support the effective and efficient operation of NTNs [7–12]. Different multiple access techniques that can be used are discussed below.

Orthogonal Multiple Access (OMA)

OMA includes technologies such as frequency division multiple access (FDMA), time division multiple access (TDMA) and code division multiple access (CDMA) [7]. FDMA was used in the 1G system, where the available spectrum was divided into single-user, non-overlapping frequency bands. The TDMA protocol, which divided time into time slots allotted to various users, was used by the 2G standard systems whereas CDMA was used in 3G systems. Specifically, CDMA serves several users concurrently in the same time frequency resources by employing user-specific codes to disperse the modulated user symbols. By separating the frequency and time resources into narrow subcarriers and time slots, which were then aggregated into resource units and assigned to the users, OFDMA was implemented in 4G and 5G systems. The following is a summary of OMA's benefits and drawbacks.

Advantages: OMA can be utilized in NTNs to more effectively enable access to various IoT devices. OMA enables these devices to seamlessly join the network and successfully manage their communications. This can make it easier to establish and operate NTN networks like satellite networks or drones. NTN IoT networks are often limited in frequency spectrum. The capacity of OMA to optimize multiple access across frequency can aid in the efficient utilization of this spectrum. This enables more devices to communicate on the same frequency band. NTN IoT networks, particularly those operating at high altitudes or in space, may require precise time and synchronization. OMA can assist devices in communicating synchronously, allowing for more dependable and accurate data delivery.

Disadvantages: Building and maintaining infrastructure for NTN networks, such as satellite networks or high-altitude balloons, can be costly. The return on investment will depend on the usage situation and the quantity of devices. Multiple access strategies, such as OMA, are frequently required for high-capacity applications, which might raise costs. Typically, NTN IoT devices have limited access to energy resources. Because the energy resources of satellites or high-altitude balloons are limited, IoT devices must cut their energy usage. Although multiple access strategies, such as OMA, are intended to enhance energy efficiency, this issue remains significant. OMA techniques have a finite number of orthogonal resources which will make it difficult to support vast NTN-assisted IoT devices.

Space Division Multiple Access (SDMA)

SDMA operates by directing communication signals to physically distinct spaces. Even while using the same frequency and time slot, this provides conflict-free communication. It is appropriate for large-scale networks such as NTN and can boost data throughput [8]. The following is a summary of SDMA's benefits and drawbacks.

Advantages: SDMA allows several users to share the same frequency and time slot. This is a big benefit when it comes to enabling large-scale IoT networks and dense device density. SDMA can effectively exploit spectrum, especially when paired with smart antenna technology. It is possible to focus the signal on certain devices while reducing interference between other devices by altering the direction of the antennas. SDMA allows for large data speeds. Ideal for IoT applications requiring high-resolution video streams or huge data transfers. SDMA, when used with smart antennas, can reduce the amount of overlap. This enhances communication quality and makes connections more dependable.

Disadvantages: Coordination and management of smart antennas and routers might be difficult. More resources and experience may be required for network administration. SDMA systems need enhanced antenna infrastructure as well as increased processing capability. This may result in higher installation and maintenance expenses. More energy can be used by smart antennas and more sophisticated CPUs. This might be a drawback for IoT devices with limited battery life. High signal-to-noise ratios may make SDMA more sensitive. This raises the possibility of poor signal quality or communication interruptions.

Non-Orthogonal Multiple Access (NOMA)

NOMA enables users to utilize resources on a subcarrier concurrently in a non-orthogonal manner by allocating codes or sending data concurrently on the same frequency at different power levels. Interleave division multiple access (IDMA), pattern division multiple access (PDMA), sparse code multiple access (SCMA), low-density spreading (LDS) CDMA, multi-user shared access (MUSA), etc. are some of the code-domain NOMA techniques. NOMA is crucial in NTN technologies for optimizing data transfer and providing greater flexibility in various access. This technology allows several people and devices to interact at the same time, enhancing communication capacity and spectrum efficiency [9]. NOMA has the ability to increase spectral efficiency in IoT applications, which is critical for supporting a large number of IoT devices. It can also improve dependability and minimize latency [10]. The following is a summary of NOMA's benefits and drawbacks.

Advantages: NOMA improves spectrum efficiency by servicing devices with varying power levels and encodings. This enables more users to interact on the same frequency while also increasing data transmission efficiency. NOMA may service numerous devices at the same time and frequency. This is essential for handling big IoT networks with dense device density. NOMA can support a variety of services. A device that requires low-speed data transmission and a device that requires high-speed data transfer, for example, can both get service on the same network. NOMA can accommodate devices with varying power and speed needs. This guarantees that different IoT devices may communicate on the same network.

Disadvantages: NOMA systems are more difficult to develop and administer than typical OMA systems. More attention is needed to manage signal intensities and coding schemes. In some circumstances, managing variable power levels and encodings might result in greater energy use. This can be a significant drawback, especially for IoT devices with limited battery life. NOMA necessitates precise power management while avoiding overlap and interference. Incorrect power control can have a detrimental impact on communication quality. NOMA implementation and management may necessitate additional computational and infrastructural expenditures. This may raise initial expenses.

Rate Splitting Multiple Access (RSMA)

For multi-antenna, multi-user communications, RSMA is a multiple access technique based on Rate-Splitting (RS) and linear precoding. User communications are divided into common and private portions by RSMA, which then encodes the common portions into one or more common streams and the private portions into distinct private streams. Each receiver decodes its own private stream after performing Successive Interference Cancellation (SIC) on the shared stream or streams. Using the portion of the message encoded in the common stream(s) and the intended private stream, each recipient reconstructs the original message. The main advantage of RSMA is that it can handle interference in a flexible manner by enabling it to be partly decoded and partially handled as noise. RSMA is especially effective in instances where IoT devices intermittently broadcast modest quantities of data [11]. RSMA is mainly useful in NTN applications that demand high-speed data transfer [10, 11]. The following is a summary of RSMA's benefits and drawbacks.

Advantages: Numerous accesses is provided by RSMA, allowing numerous devices to interact on the same frequency. This makes better use of the spectrum and allows several IoT devices to communicate data at the same time. Spectrum efficiency improves as a result. Various IoT devices might have various speeds and service requirements thanks to RSMA. Each subchannel represents a distinct method of communication, allowing for the management of variances in service quality and speed. An urgent healthcare equipment, for example, may communicate with high priority, but a less important device may communicate at a lesser pace. RSMA condenses data transmission on the same frequency. This allows for more data to be transferred at the same time. This functionality can assist IoT networks in more effectively carrying greater data payloads. RSMA may be tailored to specific applications and use circumstances. The communication speed and priority of each device may be modified, allowing for flexible network configuration. Communication between IoT devices may be accomplished with low latency via RSMA. This is critical for real-time applications, such as autonomous vehicles or medical equipment. On the same frequency, RSMA can differentiate data from various users, and security measures may be performed. This has the potential to improve data privacy and security.

Disadvantages: By dividing data and providing various communication channels for each sub-channel, RSMA necessitates a sophisticated processing procedure. This can cause communications equipment to demand greater computing power, resulting in more powerful and expensive hardware requirements. Extra control data is carried by RSMA in order to divide data and accommodate multiple communication modes. This produces system overhead in the communication

The main advantage of RSMA is that it can handle interference in a flexible manner by enabling it to be partly decoded and partially handled as noise.

IMMA has a high spectral and energy efficiency because, in contrast to the conventional NOMA method, it allows each user to transfer extra information bits (index bits) using partial resources.

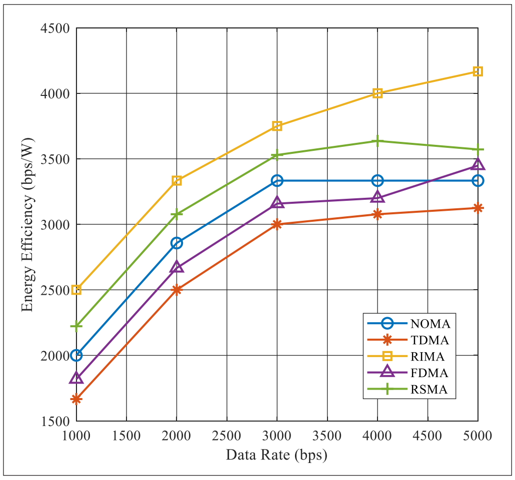

FIGURE 2. Energy efficiency against data rate for NTN-IoT.

system and increases the amount of communication data transported across the network. This can have a detrimental impact on spectral efficiency. New multiple access protocols, like as RSMA, may be incompatible with older wireless communications infrastructure and equipment. During the transition time, this may cause compatibility difficulties, and current devices may require upgrades to accommodate this new technology. To communicate extra control information, RSMA may necessitate more complexity and energy usage. This can reduce the battery life of IoT devices, particularly if energy consumption is an issue.

RIS-Indexed Multiple Access (RIMA)

RIMA is a system in which the phases of almost passive reconfigurable intelligent surface (RIS) elements are adjusted through shared information and control actions are performed by the base station [12]. By modifying the direction and phase of electromagnetic waves, RISs may shape and improve communications. These smart surfaces are used in this technology to guide communication signals and reduce collisions.

Each RIS component influences communication by altering the direction and phase of electromagnetic waves. RIS directs and shapes the communication signal transmitted to the target device. This guarantees that the signal is stronger and cleaner when it reaches the target device. RIS-Indexed Multiple Access entails RISs directing communication signals to diverse devices and minimizing device conflicts. This enables more devices to connect more quickly and reliably. RIS can improve energy efficiency by directing and shaping communications [13].

Advantages: RIS improves spectrum efficiency by more efficiently routing communication transmissions. RIS improves energy efficiency by better shaping and directing communication signals. Low-latency communication is provided via RIS-Indexed Multiple Access, which is critical for real-time IoT applications. RIS-Indexed Multiple Access is applicable to a variety of NTN IoT applications, including satellite networks, smart cities, smart transportation, and healthcare.

Disadvantages: RIS design, installation, and administration may be costly and time-consuming. Infrastructure expenses may rise when many RIS parts must be coordinated. The fact that RIS components demand energy all the time might be an issue in terms of power efficiency. Energy resources may be scarce, particularly for IoT devices working in distant or harsh environments. Specific gear and technologies are required for RIS-Indexed Multiple Access. This may need the update of current infrastructure and may render standard IoT devices unsuitable. For IoT devices running at lower frequencies, RIS-Indexed Multiple Access is more effective. Performance constraints may exist in applications needing high-frequency transmission.

Index Modulation Multiple Access (IMMA)

IMMA has a high spectral and energy efficiency because, in contrast to the conventional NOMA method, it allows each user to transfer extra information bits (index bits) using partial resources. Indexed modulation (IM) is distinguished by the use of a limited number of index values that correspond to established modulation schemes. Each index value corresponds to a different modulation constellation, which often indicates the amplitude, phase, or frequency characteristics of the transmitted signal. The index chosen specifies the precise modulation technique used for data transmission, making it an essential component of the multiple access mechanism.

Advantages: Each user can modulate their data with a different index value, allowing several users to share the spectrum resources without generating severe interference. This improves spectrum efficiency and network capacity, supporting the growing demands of 6G communications and IoT applications. IMMA also provides low power consumption and low latency, both of which are critical for IoT devices with limited energy resources and real-time communication requirements. Furthermore, because of its resilience to changing channel conditions and interference circumstances, it is a good choice for maintaining reliable communication in complicated network environments.

Disadvantages: The necessity for synchronization among users to prevent interference, the construction of effective indexing systems, and the optimization of receiver algorithms to reliably decode the transmitted data are all problems related with IMMA. These challenges necessitate additional study and development in order to fully realize the potential benefits of this method.

IMMA is a cutting-edge technique that has the potential to significantly improve the performance of 6G-enabled NTN-assisted IoT technologies by providing efficient spectrum utilization, low power consumption, and reliable communication, while also posing technical challenges that require extensive research and innovation [12, 13].

Simulation Results

Figure 2 examines the energy efficiency of RSMA, NOMA, FDMA, TDMA and RIMA techniques proposed for NTN according to data rate. The results show that the energy efficiency varies with different data rates for each technique. As a result of changing data rates, techniques such as RSMA and RIMA have offered a distinct advantage. TDMA has been found to be the least energy efficient technique compared to other techniques at variable data rates. Figure 2 also provides an important starting point for researchers looking to increase the energy efficiency and improve the sustainability of future NTN IoT networks.

Figure 3 compares the energy consumption of RSMA, NOMA, FDMA, TDMA, and RIMA approaches employed within the scope of NTN. The findings clearly demonstrate how each approach operates at various data rates. RIMA at high data rates has been demonstrated to provide great energy efficiency, it has been judged to be a good solution for IoT applications requiring high power consumption.

Each multiple access system has advantages and disadvantages, and the ideal solution to adopt will depend on the demands and network conditions of the specific IoT application. While high-data-rate systems such RIMA may be favored in high-speed and low-latency communication networks such as NTN, techniques such as NOMA or RSMA are better suited for long-lasting IoT devices that demand energy efficiency and low power usage.

Future Research Directions

The primary challenges and future research directions for multiple access schemes for NTN-assisted IoT technologies are detailed in Table 1. Future research should focus on identifying acceptable standards and regulations for 6G and NTN-enabled IoT systems, such as:

- *Heterogeneous Network Management*: Heterogeneous networks suited for diverse device kinds and service requirements will be included in 6G networks. Future research should focus on building algorithms and protocols for managing these diverse networks effectively.
- *Energy efficiency*: Future research should look on novel multiple access techniques and communication protocols to increase energy efficiency in IoT devices and NTN-enabled communications.
- *Improving Multiple Access Schemes*: Improving existing multiple access schemes and developing new schemes is critical for optimizing efficiency and spectrum consumption.
- *Security and Privacy*: With huge data flows and numerous device connections, 6G networks may bring security and privacy concerns. Future effort should concentrate on providing these networks with a strong security infrastructure.
- *Low Latency Communication*: The potential of 6G networks to deliver low-latency communications for NTN-enabled IoT products should be prioritized. This is especially important for time-sensitive applications like virtual and augmented reality.
- *Integration of AI: 6G networks will incorporate AI and ML technology*. This integration will need the creation of increasingly intelligent and autonomous systems for network management, resource allocation, and security.
- *Environmental Concerns*: 6G networks and NTN-enabled IoT technologies have the

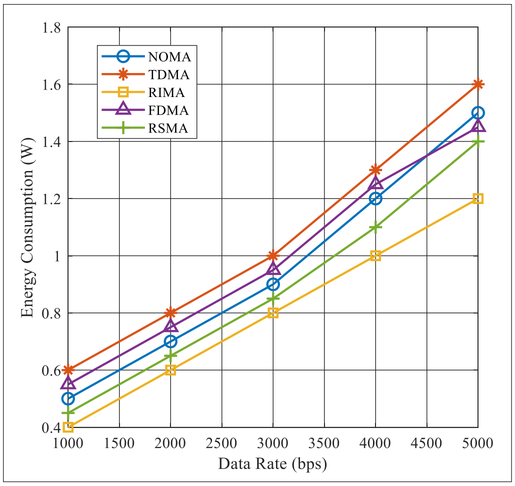

FIGURE 3. Energy consumption against data rate for NTN-IoT.

Challenges	Future Research Directions
Spectrum Insufficiency: • Need for broader frequency spectrum due to increased data speeds and device density in NTN-assisted IoT technologies	New Spectrum Resources: • Exploration and utilization of new and expanded frequency band resources. • Evaluation of high-frequency spectrum areas, including THz bands.
Energy Efficiency: • Requirement for extended battery life in IoT devices	Energy Efficiency Improvements: • Design of low-power communication protocols and processors • Improved transmission power control management for enhanced energy efficiency
Range: • IoT devices used in remote or challenging areas • Need for multiple access systems with larger coverage areas	Multiple Access Protocols/algorithms: • Development of intelligent and dynamic multiple access protocols/algorithms for greater signal transmission distances
Security and Privacy: • High-level security and privacy are crucial for communication between NTN-assisted IoT devices. • Multiple access systems must incorporate effective security measures. • Goal is to preserve data integrity and prevent unwanted access.	Quantum Assurance: • Research into the application of quantum encryption methods in IoT communications. • Development of protocols providing quantum assurance for enhanced data security.
Low Latency: • Minimal latency required in multiple access systems for certain IoT applications (e.g., driverless cars)	More Advanced Antenna Technologies: • Utilization of modern smart antenna technologies and array antenna approaches for broader coverage areas and increased data speeds. • Optimization of communication protocols and network architectures for reduced latency.

TABLE 1. Some challenges and future research directions for multiple access schemes in NTN-assisted IoT technologies.

ability to reduce environmental concerns. Research should look at how these technologies might be made more environmentally sustainable.

- *Integration with Edge Computing*: Investigating how multiple access schemes can be integrated with edge computing architectures to enhance the processing capabilities of the NTN-enabled IoT devices. This includes exploring distributed computing approaches and optimizing data offloading strategies.
- *Cross-Layer Optimization*: It will be important to investigate cross-layer optimization approaches that jointly consider the physical layer, data link layer, and network layer to enhance the overall performance of NTN-assisted IoT systems. This could include optimizing resource allocation, routing strategies, and access control mechanisms.

Conclusion

Various multiple access techniques for IoT technologies enabled by NTNs, a feature of 6G technology, are investigated in this article. The growth of NTN's communication networks using its resources, such as satellite networks and aerial platforms in space, has taken a major step toward boosting the potential of IoT applications. The effects of various multiple access strategies on NTN enabled IoT technologies were investigated in this study. The findings indicate that each access technique has distinct advantages. Each multiple access technique, however, has been determined to be better suited to various application contexts. As a result, NTN-powered IoT systems must be tailored to individual use cases.

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