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Research Article

An Investigation of Channel Estimation in RIS-NOMA with the 6G Network

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Abstract: The integration of non-orthogonal multiple access (NOMA) and reconfigurable intelligent surface (RIS) technologies is suggested as a solution to address the requirements for information rate, latency addition, and accessibility in sixth-generation (6G) networks. The two methodologies may synergistically reinforce one another to enhance the efficiency of the 6G system. Channel estimation (CE) is a significant challenge in a system that utilizes RIS. In this regard, this paper serves as a comprehensive resource for researchers, academicians, and industry professionals seeking an in-depth understanding of the framework and developments in 6G wireless technology, thereby contributing to the ongoing discourse on the future of wireless communication systems. Furthermore, this article meticulously compares the efficacy of distinct techniques employed in CE. The comparative analysis serves as a comprehensive guide, elucidating the strengths and limitations of each approach. the article contributes to the ongoing discourse on channel estimation, offering valuable insights for researchers, practitioners, and stakeholders engaged in the evolution of wireless communication systems. This article endeavors to provide a comprehensive overview of the individual merits of RISs and NOMA while delving into the synergies created through their integration. The confluence of RISs and NOMA holds the promise of overcoming existing limitations in communication networks, paving the way for unprecedented advancements in 6G. Utilizing an in-depth exploration of these paradigms, this paper contributes to the essential knowledge required for the evolution of wireless communication networks toward the 6G frontier.

Keywords: Channel Estimation, NOMA, RIS, 6G Network

1. Introduction

The foreseeable future of sixth-generation (6G) networks, which will be able to support an enormous number of devices with intelligence and numerous links between them, needs high-speed performance, low use of power, minimal delay, and energy savings. The reconfigurable intelligent surface (RIS) is a promising and unique approach that is being considered alongside multiple-input multiple-output (MIMO), millimeter-wave (mm-wave), and relay telecommunications for the development of future 6G networks [1]. In this regard, the RIS can improve the performance of cellular telecommunications by effectively reflecting and redirecting signals in controlled settings. RIS provides this with minimal hardware requirements and the potential to extend the reach of the network area. Additionally, RIS enhances spectrum efficiency, energy utilization, and speed. The RIS consists of individual components or groups of elements that autonomously manipulate the level of amplitude and phase of incoming signals in real-time to redirect energy in a specific direction [2]. Through the implementation of suitable modifications and configurations to induce phase shifts, RIS has the capability to influence the communication environment, enhance the reliability of the connection, and expand the coverage of the surrounding environment. Furthermore, RIS has the capability to function in a passive mode at an affordable price. RIS components that have little use of energy, hence enhancing the energy productivity of wireless communication networks [3].

While the exploration of next-generation multiple access (NGMA) approaches is continuous, it is advised to use non-orthogonal multiple access (NOMA) for 6G networks. The primary objective of NGMA is to provide the seamless and intelligent connection of several devices within a certain radio resource, ensuring minimal delay, stable communication, significant bandwidth, and fast data transfer rates. The current orthogonal multiple access (OMA) solutions may not be practicable for these very demanding requirements. The present OMA access strategies are limited in their ability to serve just one user in each symmetrical radio resource block. As a result, this limitation restricts the entire system's capability and maximizes spectrum utilization. The NOMA approach improves spectrum efficiency by allowing several individuals to concurrently use the same orthogonal radio asset, hence surpassing the productivity of OMA [4]. In the context of multiple-user 6G networks, which involve a large number of components, NOMA is a promising technology that could potentially be used with RIS [5]. Moreover, the power-domain-based approach utilizes the variation in channels between UEs to accomplish multiplexing [6]. A number of different investigators have looked into the channel estimation-assisted 6G network.

According to [7], the recipient is required to assess the characteristics of the channel and make adjustments to facilitate data retrieval using channel estimating techniques, including non-blind, blind, and semi-blind methods. These strategies depend on models and are created using precise mathematical channel models that include all of their characteristics. However, intricate settings provide difficulty for precise mathematical modeling of channel estimates, which could fail to accurately represent reality. The lack of precision in channel estimates is to blame for the decline in system efficiency. Therefore, this study provides a thorough examination of AI techniques used for estimating channels in multicarrier systems. Initially, we provide fundamental information on traditional methods of estimating channels within the framework of multicarrier systems. In addition, this research looks at how AI-assisted methods can be used for channel estimation, focusing on classical learning, neural networks, and reinforcement learning.

In [8]. Deep learning, a subset of artificial intelligence, has demonstrated significant potential in several fields, including picture categorization and segmentation, audio identification, and language interpretation, among others. The impressive achievement of deep learning has sparked a growing interest in using this approach for wireless channel estimation lately. Because DL works by induction, which is different from traditional rule-based algorithms, trying to use DL to channel estimates may be confusing and hard because there are so many parameters to change and you have to pay close attention to the smallest details. More precisely, the work provides many instances where the researcher conducts numerical tests to showcase the efficiency of the deep learning-based system for estimating wireless channels. According to [9], the process of estimating the characteristics of the wireless connection poses multiple challenges. The most difficult obstacle is the unpredictability of the actual channel. However, the validation root mean square error (RMSE) for the immediate channels is 0.375, whereas it is 1.116 for the cascade channels. A recent study [10] investigated that the RIS plays a crucial role in 6G networked mobile communications. This study [11,12] presents the aforementioned estimating technique, which will be iterated sequentially for each path component until all of its parts have been calculated. In the end, it may be possible to restore the broad frequency channel by computing the elements of the entire sparse channel support over all subcarriers.

Researchers [13] provided a hybrid short- and long-range channel model (HSLCM)-dependent multi-fusion based on a kernel kernel neural neural network (MF-DKCNN) for the Terahertz Ultra-Massive Multiple-Input Multiple-Output Channel Estimation technique. HSLCM channel modeling is used to find out about the path loss, azimuth and elevation angles, distance, and the steering vector of the lens array in THz propagation channels. When the DKCNN model is put together with the MF, it can be used to guess the incoming signal without any noise by using exact channel parameters and handling matrices with lots of dimensions and not much complexity. Based on the results of the evaluation, the suggested approach does better than others in terms of training data and NMSE while keeping a lower level of complexity compared to high CE outcomes. According to [14], RIS is a highly unique and groundbreaking technology that enhances the efficiency of wireless networks. Deep learning (DL) is an effective technique that may improve the efficiency of systems in RIS-based contexts by using powerful tools. Nevertheless, the limited training of the DL model leads to decreased accuracy in predicting feature information and ultimately ends in performance failure. Therefore, this study introduces a novel DL-based optimum decoding model to effectively mitigate transmission errors. However, the 1-D CNN model is implemented in order to extract attributes of the signal that was received, and these features are then processed via multiple layers to configure them.

2. 6G Wireless Technology

Wireless technology refers to the usage of devices that allow users to have the ability to move about freely. While wireless communication offers several benefits, it also entails significant hazards and challenges. Since the beginning of the twentieth century, these issues have been successfully handled over several generations. The current advancing wireless communication technology is 6G, which signifies a significant advancement from the initial 1G. Figure 1 depicts the primary advancements of 6G technology.

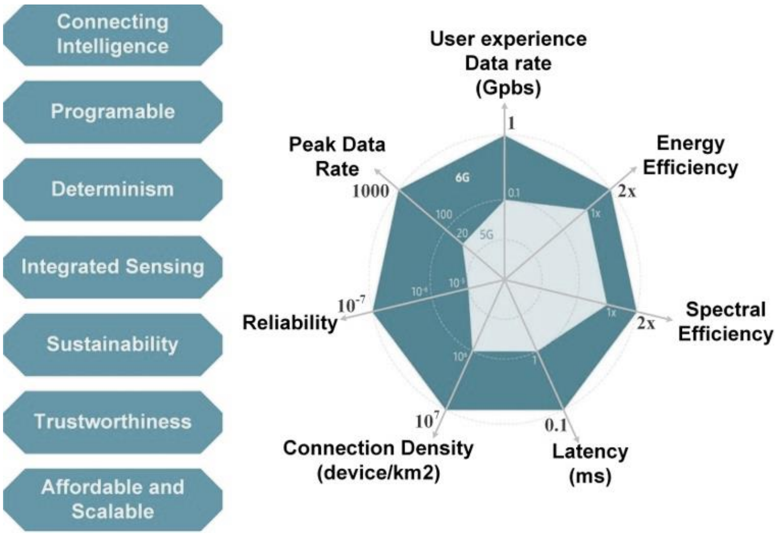

Figure 1. The main improvements of 6G technology.

The 6G technology is the key factor that will contribute to making the 6G wireless communication system feasible. Successive iterations of wireless technology are typically introduced with a time interval of about 10 years. Given the assumption that this pattern persists, it is anticipated that 6G will be integrated into our daily life by about 2030. In order to see the advancement across generations since the 1G, the overall attributes of all generations are taken into account.

A. *The framework of 6G mobile technology*

As stated before, the present capabilities of terrestrial networks are unable to meet the worldwide coverage needs for 6G. An extensive network is required, capable of including extraterrestrial networks as well, to provide a wide range of applications, including aviation and maritime activities. Figure 2 demonstrates a concise overview of the key characteristics of 6G. The architecture of 6G will be characterized by the absence of cells, significant spatial extent, and a hierarchical structure consisting of four tiers. For instance, the space network layer ensures that space internet services, which are crucial for space flight, will have coverage thanks to satellites. The terrestrial tier will deliver data transmission at speeds of Tb/s to expand the service area of 6G using THz frequency bands. Consequently, the frequency can elevate, resulting in a corresponding rise in path loss. The coverage area of 6G will be more limited compared to previous generations. To address this situation, it will be essential to deploy a greater number of base stations, resulting in a far more congested and compacted 6G network.

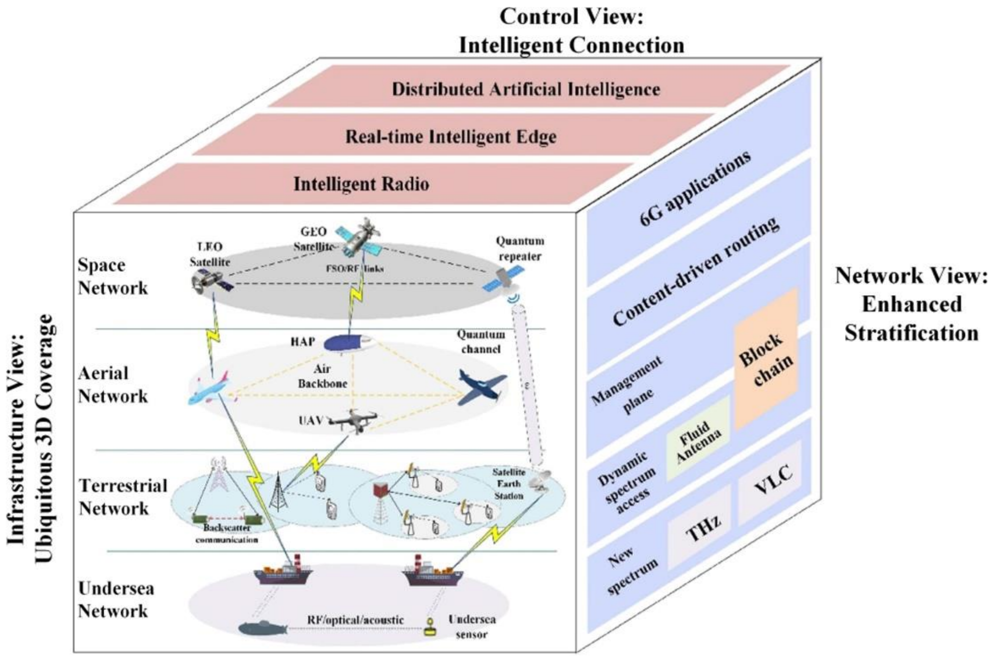

Figure 2. The key characteristics of 6G.

B. Developments in 6G networking technology

The widespread availability of 5G is anticipated to provide the foundation for the subsequent development of 6G. Upon comparing all generations, it is evident that there is a continual rise in both the speed of the internet and accessibility. The objective of 6G is to guarantee worldwide coverage. Artificial intelligence (AI) applications can stand out in 6G from prior iterations. The nascent autonomous 6G network is anticipated to function as the fundamental infrastructure for 6G technology. The forthcoming 5G capacity will demonstrate enhanced data speeds, improved security quality, and reduced latency in comparison to the existing technology. The speed of 6G is predicted to range from 1 to 10 Tbps [15].

The frequency of the current generation will be greater than that of all previous generations. The frequency gets greater as subsequent generations progress. The THz frequency indicates high transmission rates. 6G technology is expected to result in a latency range of 10–100 µs, a connection density level of ten equipment per square kilometer, and a traffic capability range of 1 Gb/s per square meter. The first tableau illustrates the disparity between 6G and its predecessors in wireless communication technologies, particularly 5G.

Table 1. The difference between 6G and the previous generations of mobile communication technologies

KPIs	6G	5G
AI	Partial	Full
Max. data	Up to one Tbps	Up to ten Gbps
Max. Frequency	10 Thz	90 GHz
coverage %	>99%	80%
Receive Sensitivity	< - 130 dBm	120 dBm
Mobility Support	1000 km/h	500 km/h
Thz communication	Limited	widely
Energy Eff.	>10x relative 5G	>1000x relative 4G
Satellite Integration	No	full

Moreover, both spectrum efficiency and energy efficiency are projected to experience exponential growth in comparison to 5G and 6G offers a wireless connection that is unrestricted and without limitations. The communication network is going to support a wide range of technologies including communication, measurement, computation, storage, supervision, GPS, radar, imaging, and navigation.

3. The Channel Estimation

Given the exponential expansion of connectivity and the increasing need for dependable communications, the issue of channel estimate (CE) has become a crucial concern. In recent times, the progress in deep learning has made it possible to do channel estimate in real-time using data-driven methods. This article discussed the methodologies used for CE in huge MIMO systems [16]. Additionally, a comparison of the different techniques used for CE is illustrated in Table 2.

Table 2. Comparison of the different techniques used for CE

Ref.	Year	Main Conclusions
[17]	[2022]	▪ This research paper proposed a two-stage scalable channel estimator (TSCE) to obtain wireless cell phone networks. The TSCE is a deep learning (DL)-based estimator that is designed to be both flexible and powerful. It consists of two DL networks, which are willing to effectively cope with various distributive allocations of resource sizes and a connection signal setup.
[18]	[2022]	▪ This research presents a novel and advanced approach for estimating the channel in close proximity for THz UM-MIMO systems. Researchers use a convolutional neural network (CNN). ▪ Considering the modeling findings, researchers can conclude that the suggested system performs better than the typical channel estimation techniques with regard to both the bit error rate and a decrease in pilot overhead.
[19]	2022	▪ The simulation findings demonstrate that the OSTM technique works as well as the traditional fixed thresholding method, despite requiring precise information regarding noise variance. The knee-point technique has comparable performance to the fixed thresholding method alone in conditions of high pilot signal-to-noise ratio (SNR). ▪ The OSTM adaptable thresholding approach is very efficient and does not experience any decrease of accuracy when contrasted with fixed thresholding.

According to [20], this study discussed a technique for CE in a distributed manner using a generative adversarial network (GAN). Researchers use Generative Adversarial Networks (GAN) to precisely predict the channels in OFDM with a reduced number of pilot signals. The RIS has an essential role as a cutting-edge technology that is facilitating the development of 6G. Despite its cost-effectiveness and energy efficiency, it is frequently utilized in coverage improvement, signal control, and other communication situations. This study [21] discussed the use of a RIS to assist a millimeter-wave communication system. The sub-pixel layer is employed as a substitute for the deconvolution layer, and the network directly receives low-resolution pictures as input. Furthermore, the denoising convolutional neural network (DnCNN) is used to further decrease the noise of the CSI. Empirical tests demonstrate that the suggested technique is very effective in accurately retrieving CSI (channel state information). In [22], the process of OFDM decoding is executed to recover the initial data that was supplied. The suggested environment is referred to as the MIMO-OFDM CE and equalization network (MOCEE-Net).

4. The Integration of NOMA And RIS Technologies

In this section, NOMA and RISs are considered crucial approaches for the 6G of wireless communication networks. RISs has the ability to effectively change the wireless propagation environment, which was previously regarded as static and unadjustable. The primary concept behind NOMA is to use the fluctuating channel circumstances of consumers in order to enhance both spectral efficiency and user fairness [23]. Both communication modalities naturally complement one another and can potentially be used to address the demanding needs anticipated for 6G networks [24]. RIS-assisted non-terrestrial NOMA systems can achieve improved outage achievements. Table 3 presents several studies that investigated the main contributions of NOMA and RIS technologies.

Table 3. Several studies investigated the Main Contributions of NOMA and RIS technologies

Ref.	Year	Main Contributions
[25-30]	2023	▪ A blind system using RIS is presented for a downlink Vehicle-to-Infrastructure (V2I) scenario. This system utilizes Fixed-NOMA. The tight correlation between the analytical as well as Monte Carlo simulation findings is evident.
[31]	2023	▪ This research puts forward an in-depth investigation, comparison, and categorization of the existing modern NOMA methods.
[32]	2023	▪ Authors propose theoretical findings to elucidate the influence of the system characteristics and clarify the level of performance improvement achieved by the combination of RIS and rate splitting (RS). ▪ This improvement is particularly notable in overrun systems. The suggested technique has significant promise for mitigating realistic channel state information (CSI) problems in networks helped by reconfigurable intelligent surfaces (RIS).
[33]	2023	▪ This research provides an in-depth strategy for analyzing the operation of coordinated (C-NOMA) systems enabled by reconfigurable RIS.

In [34], the study work determined an emerging collaborative network that utilizes RIS and NOMA technology. The analysis takes into account the fairness of users. The research effort focuses on the impact of the overall number of RIS components on the functioning of the system, particularly the power allocation of NOMA and the sum rate. Due to the challenge of obtaining the precise closed-form declaration for a given number of RIS elements, the developers instead focus on analyzing the closest approach. According to [35], the research investigation examines the coverage capability and ergodic capacity of an IoT infrastructure that utilizes a reconfigurable intelligent surface (RIS)-aided cooperative NOMA. This facilitates the enhancement of IoT systems based on 5G technology, moving towards 6G technology. Researchers derived a concise mathematical expression for the probability of near and distant user coverage, taking into account the statistical data of the channel (p-CSI) [36]. Moreover, the ergodic capacity is defined as an upper limit that simplifies the application of symbolic functions and may be used over an extended duration.

5. Challenges

The combination of RIS and NOM in 6G wireless communication systems has great potential to achieve hitherto unheard-of levels of system performance, spectral resource utilization, and network efficiency. However, there are several obstacles in the way of achieving this potential, and they must be overcome. Here is a list of some of the main obstacles to putting RIS-assisted NOMA systems into practice in this section.

- Channel Approximation: Effective communication in RIS-assisted NOMA systems depends on precise estimation of the channel state information (CSI). The fact that there are more users and channels involved makes this challenge even more severe.
- Intricate signaling plans: Because RIS-assisted NOMA systems have multiple users and channels, they require complex signaling protocols to be implemented. A significant challenge is creating effective signaling schemes with low overhead and robustness against channel variations.
- Design of Hardware: Large-scale RIS deployment presents major hardware design challenges, especially in terms of manufacturing complexity, cost, size, and power consumption. For RIS to be widely used, affordable, small, energy-efficient, and mass-producible components must be developed.

- Strategies for Dynamic Optimization: Optimizing the performance of RIS-assisted NOMA systems requires the ability to quickly adjust to changing channel conditions. Real-time optimization techniques, however, call for powerful computers and quick feedback systems.
- Effective interference management is essential to preserving reliability and fairness in multi-user NOMA systems. User priorities, channel circumstances, and resource availability should all be taken into account by effective interference management strategies.
- Security Considerations: To safeguard private data sent over the air interface, security in RIS-assisted NOMA systems is crucial. Eavesdropping, jamming, and impersonation attacks are examples of possible threats.
- Scalability: Another major challenge is scaling up RIS-assisted NOMA systems to support large numbers of devices and users. The complexity of signal processing, network architecture, and resource allocation are problems that need to be addressed by effective solutions.
- Combining Other Cutting-Edge Technologies: While there are many advantages to combining RIS-assisted NOMA with other cutting-edge technologies like satellite communications, terahertz technology, and millimeter wave communications, there are also new difficulties with synchronization, control, and compatibility.
- Standards and Regulation Problems: Complying with current regulations and industry standards while implementing RIS-assisted NOMA systems is crucial to guaranteeing safety, interoperability, and compliance.

Realizing the goal of ultra-reliable, ultra-low latency, and ubiquitously connected 6G wireless communication networks will depend on overcoming these obstacles and designing and running RIS-assisted NOMA systems optimally.

6. Opportunities

Even though there are some problems, adding RIS and NOMA to 6G wireless communication systems opens up a lot of exciting chances to make wireless networking even better than it is now. In this direction, researchers explore some of the most promising opportunities offered by RIS-assisted NOMA systems.

- Spectral Efficiency Improvement: RIS-assisted NOMA has better spectral efficiency than traditional orthogonal multiple access (OMA) methods because it lets multiple users send data at the same time without interfering with each other.
- Energy Savings: The use of RIS for signal reflection instead of direct transmission from the base station (BS) to user equipment (UE) reduces the amount of required transmit power, leading to significant energy savings.
- Increased Coverage: RIS-assisted NOMA enables extending coverage to hard-to-reach areas where conventional cellular infrastructure may not provide adequate service. This capability is especially important for supporting IoT applications and rural communities.
- Faster Data Transmission Speeds: With the ability to serve multiple users simultaneously, RIS-assisted NOMA systems can achieve significantly higher data transfer rates than their OMA counterparts.
- Better Network Reliability: RIS-assisted NOMA systems can make networks more reliable and available by improving the quality of the radio propagation environment. This makes them suitable for mission-critical applications.
- Reduced Latency: By minimizing the time it takes for data packets to travel between the BS and UEs through the use of RIS, RIS-assisted NOMA systems can deliver reduced latencies, which is essential for supporting real-time applications like autonomous vehicles and telemedicine.
- Enhanced System Capacity: RIS-assisted NOMA's ability to serve multiple users concurrently increases the overall system capacity, allowing for greater scalability and flexibility in meeting the growing demand for wireless services.
- Seamless Handover: RIS-assisted NOMA systems can facilitate seamless handovers between cells, reducing call drops and improving the overall user experience when moving around within a network.

- Cost Savings: By utilizing RIS for signal enhancement rather than deploying new infrastructure, operators can save costs on building and maintaining cell sites, particularly in densely populated urban environments.
- New Applications and Services: RIS-assisted NOMA opens up possibilities for novel applications and services, including smart cities, industrial automation, augmented reality, virtual reality, and immersive gaming experiences.

Thus, the combination of RIS and NOMA in 6G wireless communication systems represents a transformative leap forward in terms of network performance, efficiency, and functionality. Addressing the challenges discussed earlier and capitalizing on the opportunities presented will be critical for unlocking the full potential of these innovative technologies.

7. Conclusion

To begin with, 6G wireless communication systems promise to bring about unprecedented accessibility, ultra-low latency, and high data rates, thereby revolutionizing the way we connect and communicate. Novel technologies like RIS and NOMA have emerged as viable options to meet these goals. The researcher gave a thorough explanation of the core ideas, benefits, and uses of both NOMA and RIS in the context of 6G wireless communication systems in this article. Researcher proves that the system is able to increase spectral resource utilization, boost network efficiency, and improve overall system performance by integrating NOMA and RIS. The combination of these two technologies has demonstrated significant promise in enabling cutting-edge features such as intelligent caching, massive MIMO, and full duplex communication. However, precise channel estimation (CE) is crucial for the effective operation of RIS-assisted NOMA systems. Researcher compared several CE techniques in this regard, such as compressive sensing techniques, deep learning algorithms, and pilot-based methods. There are particular benefits and trade-offs associated with each technique in terms of complexity, accuracy, and flexibility. When developing and implementing RIS-assisted NOMA systems, researchers and engineers will be better able to make decisions if they are aware of these features.

Even with the advancements in this field, several issues still need to be resolved before RIS-assisted NOMA systems in 6G networks can reach their full potential. These include dynamic optimization techniques, intricate signaling schemes, and hardware design-related problems. Experts in interdisciplinary fields including electrical engineering, computer science, mathematics, and material sciences must work together to address these challenges. In conclusion, a thorough analysis of the integration of RIS and NOMA technologies in 6G wireless communication systems was provided in this article. The researcher addresses about how these two innovations work well together and how important CE is to maintaining good communication in RIS-assisted NOMA systems.

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