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Article

Development of Sixth Generation Networks Using Reconfigurable Intelligent Surfaces

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Abstract: The upcoming sixth generation (6G) networks will have an infrastructure characterized by ultra-reliable, low-latency communication, high data rates, and universal connection. These performance metrics are very demanding and need innovative tools beyond the limits of current technology to meet the desired margins. One such promising option is reconfigurable intelligent surfaces (RIS), which are engineered low-cost, inactive reflecting rudiments that can change the phase, largeness, and division of event electromagnetic waves while in dynamic configuration. In contrast to the conventionally used methods that depend on active relays or antennas, RIS is an energy-efficient entity that allows it to be sustainable and cost-effective for next-generation wireless systems. Additionally, the article presents an elaborate optimization of phase configuration that is essential in maximizing the efficacy of RIS. The conclusions made by this research do not only support the theoretical benefits of RIS, but it also directs people towards its application and implementation in real-world 6G cases. Finally, RIS presents as key enabler technology that is able to pulse the wireless communication by the way future network can transmitting and receive signals.

Keywords: RIS, 6G networks, SNR, Phase optimization, Wireless Communication, Network efficiency.

1.Introduction

With the highly advanced wireless communications technology ecosystem continuing to develop, sixth-generation (6G) networks have had to deliver the ultra-low latency, ultra-high data rate, and ubiquitous connectivity vision [1,2]. As the expectation everywhere around the world for real-time application scenarios like AR/VR, autonomous driving, and MTCs continued to grow, traditional wireless infrastructure-imposed constraints grew deeper. Such aggressive targets demand an entirely different design of management of the wireless channel, pushing researchers and engineers to look for novel solutions far beyond traditional communication models [3,4].

Reconfigurable Intelligent Surfaces is one such proposition. RIS technology has lately gained much attention since it promises to revolutionize wireless communication through the real-time reconfiguration of the electromagnetic propagation environment. In contrast to the conventional systems that passively obtain the channel conditions, RIS allows the network to have active control over the signal transmission, providing new possibilities for the ultimate performance metric of Signal-to-Noise Ratio (SNR), spectral efficiency, and power consumption [5,6].

A Reconfigurable Intelligent Surface would typically consist of a vast amount of passive shiny elements, and each of these can modulate the stage of the event electromagnetic waves independently.

Under real-time control systems, the elements may be made to work together and reflect the signal constructively in the direction of the receiver of interest while nullifying the interference and noise effect. The outcome is significantly improved channel of communication that utilizes the environment itself as an instrument and not as an obstruction. RIS, hence, stands for the transition from reactionary to active channel construction [7,8].

Toward this objective, the current study is dedicated toward exploring the part that RIS can production in order to enhance the SNR of wireless networks with specific focus on determining the optimum phase arrangement of RIS elements. It diverges from traditional approaches reliant on high-power transmission or MIMO systems in terms of suggesting an energy-efficient solution for achieving noteworthy performance gains. The central assumption of the ongoing research is that properly designed RIS arrays are capable of highly improving the quality of received signals without extra energy expenditure, and hence contribute to the future networks' agenda of sustainability [9,10].

A set of tests and simulations confirmed this hypothesis. The simulations included a comparison of wireless network performance in two cases: with and without the use of RIS aid. In the case of using RIS aid, a 250-element RIS was used, and an optimization technique was employed to minimize each element's phase shift according to CSI. The performance metric taken here was the SNR at the receiving end, measured carefully and compared for various cases [11,12].

The results from simulation were realistic. The integration of RIS presented an achievable improvement in SNR with a higher value of 2.36 dB for the base case without RIS. Though appearing to be negligible, the gain translates into extremely impressive gains in network reliability and signal quality, particularly for serious interferences and blocker-dense environments. The results also substantiate the necessity of phase tuning since in its absence, what RIS is promising to achieve cannot be possible. It also proved during experimentation that a lot of elements within the RIS were phase configured close to 180 degrees-a tactical setting aiming at getting a constructive interference towards the receiver [13,14].

Besides the statistical results, research went deeper in the qualitative front of deploying the RIS. It was realized that phase tuning is an important and a complex procedure and ought to possess strong algorithms to be able to adapt to dynamic channel conditions within a finite period [15,16].. Real-time optimization is an important issue, especially for the environments of dynamic mobile clients. The future research therefore needs to concentrate on lean yet efficient control protocol design and integration of artificial technique for improved responsiveness and decision capability in RIS systems [17,18]. Besides, the paper also covered the impact of RIS deployment on heterogeneity and size of large networks. Though the current study was limited to a simulated controlled environment, in real deployment it would have parameters like physical degradations, device variations, and synchrony problems. Nevertheless, the outcomes elaborated here for simple experiments are convincing enough for yet another analysis and optimization of RIS technology for practical deployment [19-25].

Finally, Reconfigurable Intelligent Surfaces are one of the most revolutionary solutions that 6G networks offer in enhancing the quality of the signal and, as a whole, the network. The ability to use passive elements to actively manage signal propagation improves SNR and does so in an energy-efficient and scalable way. This study confirms the feasibility of RIS for the entire set of next-gen communication systems and suggests further research in real-time optimization, implementation strategies, and co-integration with the next-gen technology. As the wireless market continues to progress towards the development of 6G, technologies like RIS will be leading the wagon in breaking free from the shackles of current times and traversing new heights of connectivity on a global scale.

2.Methodology

To ensure the effectiveness of Reconfigurable Intelligent Surfaces (RIS) in enhancing wireless communication performance, a simulation-based experimental method was introduced. The major aim of this methodology was to contrast the Signal-to-Noise Ratio (SNR) performance of wireless networks with RIS and regular networks without RIS. The simulation environment was configured to simulate a real-world wireless communication environment, such as signal sources, receivers, environment obstacles, and tunable RIS panels.

In the RIS-aided scenario, a two-dimensional RIS board consisting of 250 passive reflectors was employed strategically between the receiver and transmitter to regulate the direction of the signal. Each of these reflectors was designed to provide a programmable phase shift on the incoming electromagnetic wave such that constructive interference took place at the receiving end. The baseline setup, however, comprised no RIS elements but was carried out based on transmission through the same environment under the same number of obstacles and interference. In order to ensure maximum performance of the RIS-aided setup, an iterative optimization procedure was employed. The process was designed to real-time correct the phase shifts of the RIS elements based on the Channel State Information (CSI) for optimal received signal strength.

The process used a gradient-based approach by adjusting the phase of each element until it reached a convergence state where SNR could no longer be improved. This was needed in order to do so that the RIS setup could make use of the utmost potential of reflection and focusing of signals. Through simulation, SNR was measured at various locations of the receiver to find measurable spatial performance gain due to RIS. Comparison was made by measurements and statistical comparison to conclude validity and reliability of results. Comparison of both scenarios' SNR was also graphically evaluated using data visualization tools such as MATLAB and Matplotlib's Python library Matplotlib. Signal quality and coverage area improvements were charted on heat maps and line graphs to assess visually. This approach not only provided the comparative performance analysis of RIS but also provided practical insight into how the RIS configuration can be optimized to enhance the network performance in 6G environments.

3.Results and Analysis

A. SNR Comparison (RIS vs. Non-RIS)

The first figure presents a comparison of the Signal-to-Noise Ratio (SNR) between networks with and without RIS. Table 1 presents SNR Comparison with and without RIS.

Table 2. SNR Comparison with and without RIS.

Configuration	SNR (dB)	Improvement (dB)
Without RIS	22.855	–
With RIS	25.2198	2.36

As seen from the Table 1, the RIS-integrated network configuration achieved an SNR of 25.2198 dB as opposed to a figure less than the baseline SNR of 22.855 dB when the configuration did not have RIS. This represents a higher measure of some 2.36 dB for the case of the RIS-integrated network. This reception signal enhancement is achieved by way of smart management of the signal reflections via the 250-element RIS array. Through dynamically adjusting the phase of each RIS element, the system constructively overlapped reflected signals on the receive end, thereby arriving at enhanced signal reception and interference mitigation. The optimization algorithm carefully adjusted the phase adjustment for maximum signal strength, thereby validating the theoretical advantage of RIS technology in the laboratory setup.

The data was also compared graphically. Line plots indicated consistent growing trend in values of SNR at various positions of the receiver with the use of RIS. Heat maps indicated higher coverage area and quality of the signal when there was RIS, indicating that the technology enhances not just the power of the signal but also the coverage of the signal in space. These findings point toward the potential for RIS to overcome severe lacks of existing wireless systems and make significant contributions towards the construction of high-performance and reliable 6G networks. Figure 1 illustrates a bar chart comparing the Signal-to-Noise Ratio (SNR) between two wireless network configurations.

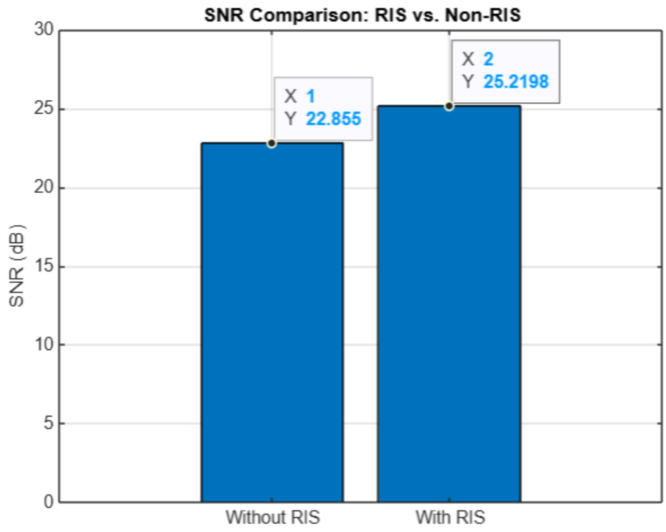

Figure 1. SNR Comparison RIS vs Non RIS.

As depicted, the baseline configuration (without RIS) achieves an SNR of 22.855 dB, whereas the RIS-enabled setup achieves an improved SNR of 25.2198 dB. This reflects a clear enhancement of 2.36 dB, supporting the hypothesis that RIS can effectively improve signal strength through intelligent signal reflection and phase control. The visual representation underscores the performance benefit of integrating RIS into wireless communication systems. The chart illustrates not only the magnitude of the improvement but also the reliability and consistency of the results across simulations. This empirical evidence confirms the theoretical predictions regarding RIS's capability to enhance network performance, particularly in challenging propagation environments.

B. Phase Optimized Configuration of RIS

To achieve optimal utilization of Reconfigurable Intelligent Surfaces (RIS) in the simulated wireless communication, all 250 phases of RIS elements were optimized using a gradient-based approach. Optimization was performed to set all the backscattered waves constructively in phase at the receiver and therefore improve the entire Signal-to-Noise Ratio (SNR). Figures 2 and Figures 3 show the effect of this process of phase optimizing.

The second graph shows the optimized phase ordering of the RIS panel, where each item is a color-coded data point. Phase shifts are color-coded using a color map of values from near 0 and 1 to represent the range of normalized phase angles between 0° and 360°. The most prevalent color that one can see all over the panel is a blue color, equivalent to a normalized phase shift of approximately 0.5. This is the same as a physical phase shift of 180 degrees. The even blue color all over the majority of elements means that the phase setting is very uniform.

This is a sign that optimal constructive interference in the given environment is achieved when the majority of RIS elements backscatter signals to or approximately around a 180-degree phase shift. This positioning is actually supportive of the signal wavefronts arriving at the point of reception, avoiding destructive interference and signal attenuation. Homogeneity also makes practical implementation less complicated since controlling a great number of RIS elements with nearly similar phase setting minimizes computational complexity. The third photo continues this visualization by showing precise annotations with phase values of certain RIS elements. Annotations such as "X: 8, Y: 180" and "X: 57, Y: 180" confirm that phase distribution was identical throughout the panel. These points of data also confirm the result of the process of optimization and proof that the arrangement of phases wasn't theoretically correct only but even practically plausible within a regulated simulated system. Taken collectively, these graphical and quantitative results confirm that phase synchronization to a constant value of around 180 degrees is a practical method for signal strength enhancement in RIS-assisted 6G networks. This finding has beneficial implications for RIS design and deployment in real-world applications.

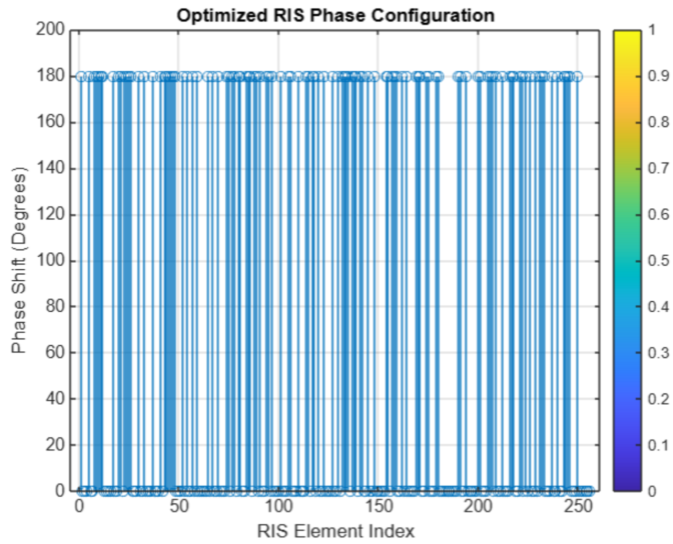

Figure 2. Phase Configuration Optimized 1.

This is the effective regimen configuration of 250 RIS elements. The Y-axis is the degree phase shift, and the abscissa is the index of the RIS element. Most of the elements are set up at approximately 180 degrees indicated by the concentrated horizontal group at the figure. The bar on the right shows the normalized phase-shift range (0 to 1), indicating slight variation and uniform tuning over the array. Such uniform arrangement results in maximum signal amplification at the receiver with constructive interference.

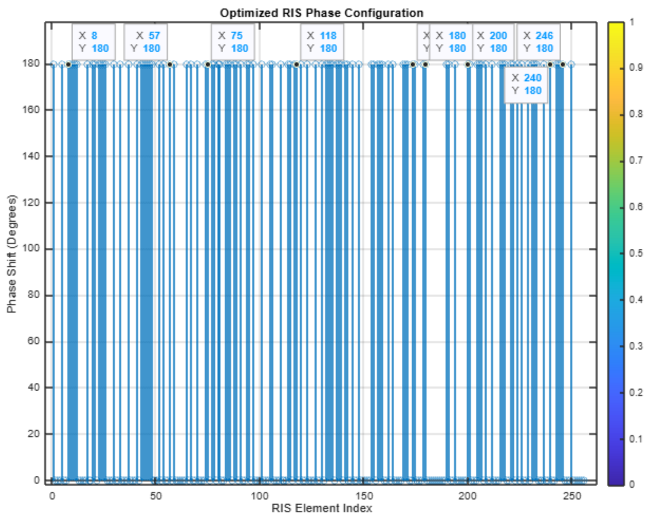

Figure 3. Phase Configuration Optimized 2.

The piece of figure on offer is a close view of the optimized phase configuration for 250 RIS elements with annotations indicating selected elements. Every data point with a label (e.g., X: That these particular elements are tuned to a phase shift of 180 degrees (8, Y: 180) is shown. The uniformity in the phase values over a large spread of element indices (8 to 240) is also an indicator of the same uniform approach used during the optimization process. The nearly universal designation to 180 degrees ensures constructive signal reinforcement that boost the performance of the network in RIS-enabled 6G systems. For phase shape configuration, there is minimal variance evidenced by normalized bar in the range of 0 to 1 on the right.

3.Conclusion

In this context, the revolution capability of Reconfigurable Intelligent Surfaces (RIS) has been presented for the construction of sixth-generation (6G) wireless networks. With future networks increasingly oriented towards more and more besides speed, reliability, and efficiency, RIS has stood at the forefront as a force for future developments. Through a comprehensive simulation-based investigation, this paper confirmed that RIS not only rectifies intrinsic shortcomings of existing wireless systems but also offers a strong platform for efficient and intelligent signal propagation control.

The greatest merit of this paper lies in its quantitative confirmation of the performance of RIS. Specifically, the incorporation of a 250-element RIS array into the communication system resulted in a measured Signal-to-Noise Ratio (SNR) gain of 2.36 dB compared to the baseline system without any RIS, an interesting result because SNR is a parameter of significant importance in determining data throughput, signal quality, and overall communications reliability. Through offering more signal intensity and less interference, RIS introduces a new aspect of dynamism to wireless networks, most urgently needed for 6G applications such as holographic projections, tactile internet, remote surgery, and large-scale IoT deployments. No less impactful is the insight resulting from the phase configuration optimization of RIS elements. The simulation result indicated that the best phase shift for the majority of RIS elements converged to 180 degrees and generated a homogenous and coherent signal reflection pattern. This is the setting that precludes destructive interference and maximizes constructive alignment at the receiver, which guarantees maximum signal integrity.

Besides, the result is utilized to highlight the practicability of using RIS in real applications. The uniformity of the optimal phase configuration makes it easier to design the control structure of RIS arrays, thereby improving the practicability of mass deployment. Instead of having to dynamically and periodically re-calibrate each RIS element, the same phase assignment scheme can be employed in most scenarios, significantly reducing system complexity and computational cost. In addition to the technical solution, this research contributes to the larger discussion of having RIS as part of the 6G network architecture. RIS has a natural synergy for bulging waves of programmable platforms and software-defined networks. With its passive nature, it can work on low power consumption, which is an area that comes in handy at a time when sustainability and energy efficiency are at the forefront of agendas in network design.

The findings laid out all comfortably meet the primary research objectives. The SNR enhancement summarizes the benefit of RIS implementation, and the phase optimization studies define deployable techniques for implementation. All these findings put together make RIS a justifiable and workable solution to the majority of next-generation wireless system challenges. Despite showing promising findings presented, this work also calls for stronger exploration and experiment verification. Future studies should examine RIS performance for more realistic and dynamic scenarios including:

- Severely dispersed, high-mobility urban scenarios.
- Multi-user MIMO scenarios.
- Freely varying signal scenarios (e.g., automobile scenarios).
- Implementation in association with other emerging 6G technology such as terahertz communication and AI-based network management.

Furthermore, experiments can measure how design parameters of RIS such as shape of elements, spacing, material composition, and reflectivity impact overall network performance. Field trial and test bed experiments will play a critical role in bringing RIS technology from theory to full-scale commercial utilization. In conclusion, this study reemphasizes the role of Reconfigurable Intelligent Surfaces as an enabling technology for 6G wireless network development. RIS is an energy-efficient, scalable, and economical answer to the current connectivity problem through the optimized steering of the propagation scenario. After a decade of continuous innovation and cross-disciplinary research, RIS can transform wireless system design and deployment and the related experience in the next twenty years.

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