

Dynamic coverage optimization using 3D position-controlled Reconfigurable Intelligent Surfaces in 6G networks

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Abstract—Reconfigurable Intelligent Surfaces (RIS) are one of the promising technologies in wireless communications. They allow controlling how wireless signals are reflected on smart surfaces, which helps improve coverage and increase network efficiency. Although most current research use RIS models fixed to walls, but this design may not always be the best option for achieving optimal coverage, especially in environments where user density changes frequently. In this research, we propose an adaptive RIS model that can change both the vertical height and the horizontal steering angle (azimuth) in an intelligent way, based on user locations or the load in each area. This model is supported by signal quality indicators such as the Received Signal Strength Indicator (RSSI), which is measured at the user side and used as feedback to determine the best RIS orientation. The proposed RIS model was implemented in MATLAB and tested in two scenarios according to user locations, comparing the performance of a fixed RIS with that of an adaptive moving RIS. Simulation results for both scenarios showed that increasing the RIS height from 5 to 15 meters helped double the received signal power for some users, while adjusting the horizontal steering angle from 0° to 45° increased the received power from -104 dB to -94 dB, which is more than eight times the power in the case of a fixed RIS. These results confirm that using a 3D repositionable RIS is a practical step toward improving wireless performance system, especially in 6G environments that are complex and continuously changing.

Keywords—Reconfigurable Intelligent Surface (RIS); RIS height adjustment; RIS azimuth angle; RSSI; Smart Feedback; SNR; Dynamic RIS configuration; CQI; Artificial Intelligence; 6G; NLOS conditions; mm-wave

I. INTRODUCTION

Traditional wireless networks often suffer from the impact of natural obstacles such as buildings and trees, which limit coverage and signal quality—especially in complex environments filled with such obstructions. This can lead to weak or completely lost connections, making it difficult for the network to meet the growing demand of users and support modern communication applications. For example, some buildings in the signal path, can cause a drop in received power of up to 30 dB, especially at high frequencies around 3.5 GHz. This has created the need for solutions to overcome such challenges. One solution is Reconfigurable Intelligent Surfaces (RIS), which can redirect signals and improve coverage by up

to 200% in some cases, without the need to expand the traditional network infrastructure [1].

RIS is made from many small electronic parts. They are all on one flat panel. Each part can change the signal angle or its phase by electronic control.

These parts send the wireless signal in the right way to reach users. Some new tests showed one type of RIS with filtering. It blocked over 20 dB of signals that were outside the needed band. This happened at 3.5 GHz. The quality factor was $Q = 14$. This helps the signal go to places with no direct line of sight (NLOS), like in Figure 1. With this, the network can be better without more base stations. It also saves power. This makes RIS useful for modern communication [2], [3], [4].

The core principle behind RIS is to modify the properties of reflected waves to direct them accurately toward the receiver [5]. This is achieved by programming the electronic elements on the RIS surface to adjust the phase of the reflected signal, creating constructive interference at the receiver. The effectiveness of this control depends mainly on the angle of incidence (θ_i) and the angle of reflection (θ_r) [6].

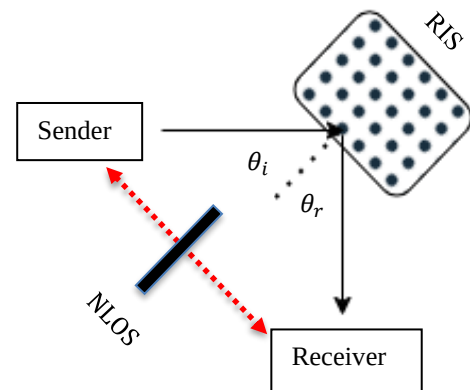


Fig. 1. RIS for NLOS Scenarios

The reflected beam direction comes from the angle it arrives. The reflection angle decides where the signal goes to the receiver. The beam works better when the phase shifts for each array element are set carefully. Setting the phase shifts in steps

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of 45° or less can make the received power more than 5 dB higher in some places. This clearly increases the signal strength [7]. Smart control over the reflection properties helps improve communication performance and fills coverage gaps—especially in urban areas where tall buildings and limited space make it difficult to install new towers. It also supports more flexible deployment at lower cost and with better efficiency [8], [9]. Simulation is an important role for studying (RIS). It helps researchers to understand how this technology works, and test its effect on improving coverage and reducing interference before using it in real networks. For example, some studies showed that changing the reflection angle from 0° to 60° in a city environment can increase the received power by more than 8 dB. Tests also found that using an RIS panel with 256 elements and accurate phase control can improve the Signal-to-Noise Ratio (SNR) by up to 10 dB. Therefore, it is possible to set the best settings that give better connection quality with the least effort and cost [10], [11], [12].

wireless systems use quality indicators to evaluate signal network. Received Signal Strength Indicator (RSSI) is one of these indicators, which provides a power level of received signals. Signal-to-Noise Ratio (SNR) is used to express level of signal relative to noise. The Channel Quality Indicator (CQI) is also used to evaluate the wireless channel. These indicators sent from the user device to the base station as part of feedback mechanisms to improve RIS performance. Furthermore, integrating these indicators with artificial intelligence algorithms can enhance network efficiency—especially in complex environments such as smart cities and indoor buildings [13], [14], [15], [16].

In this study, simulation was used to evaluate the effect of dynamically changing the height and azimuth angle for the RIS. Various scenarios used to improve coverage and to test the effective dynamic RIS before practical implementation. The main contributions of this work are explained below:

1. Proposal adaptive model of RIS: This study proposal a new idea for automatic adjustment of the RIS height and azimuth angle based on the users' locations or traffic load in each area. This adaptive control achieves better coverage without the need for additional infrastructure.
2. Evaluation of the dynamic RIS : Simulation results showed that changing the RIS height and azimuth improved the received signal strength, especially in environments where there is no direct line of sight (NLOS). This confirms the practical benefit of the proposed approach.
3. Integration of theoretical and simulated analysis: The work combines theoretical results with simulation results obtained using MATLAB, providing a strong foundation for future comparative studies.

This paper is organized into several main sections. Section II reviews the most relevant related work on RIS technology and highlights research gaps that this study aims to address. Section III presents the mathematical model of the RIS, including key equations describing the reflected signal behavior. Section IV outlines the assumptions and parameters used in the simulation

model, such as the positions of the transmitter and users. In Section V, the simulation results are presented, showing the impact of mechanically adjusting the RIS on the received signal. Finally, Section VI summarizes the key findings, and Section VII discusses potential future directions for improving the proposed model.

II. RELATED WORK

This paper presents a new simulation-based model designed to study the effect of dynamically changing both the azimuth angle and vertical height of a Reconfigurable Intelligent Surface (RIS) on the received signal power. The goal is to explore the potential of adjusting RIS characteristics flexibly and efficiently based on user locations and the surrounding environment, using MATLAB-based simulations. While this model opens new directions for deploying RIS more intelligently, many previous studies have mainly focused on static or theoretical evaluations of RIS performance in wireless communication.

For example, study [17] explored the basic principles of using RIS technology. The results showed that integrating RIS into network infrastructure can increase spectrum utilization efficiency by approximately 3.3 times in some cases, while improving the signal-to-noise ratio by approximately 8 dB. Study [18], on the other hand, focused on a practical aspect by building and testing a real RIS prototype operating below 6 GHz, aiming to demonstrate its practical benefits in a real-world setting. Study [19] discuss an important challenge in RIS systems—carrier frequency offset (CFO) in multi-user settings. The results showed that when the offset reaches 0.1, the error rate can go up by more than 20%. Study [20] proposed using an active RIS for integrated sensing and communication (ISAC), introducing a beamforming approach to boost radar signal strength and cut down interference. Both theory and simulations showed that the active RIS outperformed the passive RIS by 5 dB in these scenarios. Study [21] introduced a new concept called Plug-In RIS, which is a fully passive RIS designed to be placed in an optimal location and configured only once based on the positions of the base station and users. This allows coverage improvement without any internal power on the RIS. Furthermore, reference [22] compared active and passive RIS to see which works better for 6G networks. They found that a passive surface can lose up to 30 dB of signal strength, while an active surface can make up for this by improve the reflected signal by 20 dB, giving best performance. In [23] an idea of a Beyond Diagonal RIS was introduced, where the surface elements are linked together instead of traditional designs. The results showed that this setup can increase signal gain by about 3–4 dB and improve beamforming efficiency by around 15% compared to standard models. Later, In [24], the performance of non-diagonal RIS designs was studied. The results showed that the losses could reduce by 2–3 dB, and the performance improved by about 2 dB compared to traditional tuning methods.

Table I presents a brief comparison of the reviewed studies in terms of whether they relied on theoretical analysis, simulation, or both, as well as the type of RIS technology used in each.

TABLE I
Position of the Current Study in Relation to Existing Literature.

REFERENCE	YEAR	THEORETICAL	SIMULATION	RIS TYPE		
				PASSIVE	ACTIVE	ADAPTIVE
[17]	2020	✓		✓		
[18]	2022	✓	✓		✓	
[19]	2022	✓	✓	✓		
[20]	2023	✓	✓	✓	✓	
[21]	2023	✓	✓	✓		
[22]	2023		✓	✓	✓	
[23]	2024	✓	✓		✓	
[24]	2024	✓	✓	✓		
OUR PAPER	2025	✓	✓	✓	✓	✓

III. RIS MODELING

Reconfigurable Intelligent Surfaces (RIS) offer an effective solution for improving wireless coverage in environments where the direct line of sight (NLOS) between the transmitter and receiver is blocked. In such cases, the signal reflected by the RIS is often stronger than the signal received through indirect paths. The received signal via the reflecting surface depends on several physical and engineering factors, which can be described by the following equations [25], [26], [27]:

$$P_r = \left(\frac{\lambda}{4\pi D_{sr}} \right)^2 \cdot \left(\frac{\lambda}{4\pi D_{ts}} \right)^2 \cdot P_t \cdot G_t \cdot G_r \cdot A^2 \cdot \cos(\theta_i) \cdot \cos(\theta_r) \quad (1)$$

$$A = N \cdot d^2 \quad (2)$$

Where:

P_r : received power (watts).

P_t : The transmit power (watts).

G_t : transmitter gain

G_r : The gains of the transmit and receive

A : effective reflecting area of the RIS,

N : number of reflecting elements,

d :side length of each square element.

θ_i : angles of incidence

θ_r : angles of reflection

D_{ts} : distances from transmitter to RIS

D_{sr} : distances from RIS to receiver

These equations are mainly used to describe the theoretical behavior of RIS and provide a mathematical foundation for comparing theoretical outcomes with simulation or real-world results. Based on the received power, key signal quality indicators such as RSSI, SNR, and CQI can be derived. These indicators are widely used in modern communication systems to assess signal quality and play an essential role in making intelligent decisions for RIS beam steering and performance enhancement [28], [29], [30].

$$RSSI_{(dB)} = 10 \cdot \log_{10}(P_r) \quad (3)$$

$$SNR_{(dB)} = 10 \cdot \log_{10} \left(\frac{P_r}{P_n} \right) \quad (4)$$

$$CQI \approx \alpha \cdot \log_2(1 + SNR) \quad (5)$$

Where:

RSSI: Received Signal Strength Indicator (in decibels).

SNR: Signal-to-Noise Ratio (in decibels).

CQI: Channel Quality Indicator.

α : Scaling factor for modulation bandwidth.

These equations are mainly used to describe the theoretical behavior of RIS. It is providing a mathematical basis for comparing theoretical results with simulation or practical results. In this study, a wireless communication system was simulated using MATLAB with RIS technology, as shown in Figure 2, to analyze how adjusting the reflection angle and the height of the RIS surface can improve the received signal by mechanically controlling for high and azimuth for the RIS.

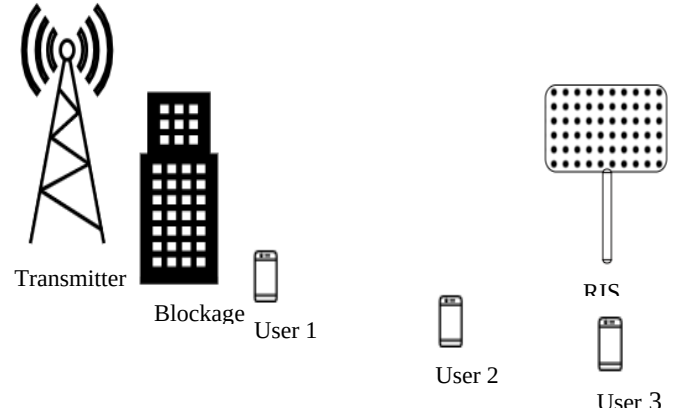


Fig. 2. RIS-Assisted Communication Model

IV. ASSUMPTIONS AND PARAMETERS

The simulation model assumed the presence of an obstacle blocking the direct line-of-sight path between the transmitter and the users, making the Reconfigurable Intelligent Surface (RIS) the optimal path for signal transmission. The Free-Space Path Loss (FSPL) model was used to represent the wireless channel, without considering shadowing effects or random interference. Additionally, no external interference from other transmitters was included. For simplicity, isotropic antennas were used for both the transmitter and the receivers. The RIS was modeled as a flat matrix consisting of 15 rows and 10 columns of reflecting elements, with a spacing of half the wavelength between each element. With an operating frequency of 2.6 GHz, this spacing corresponds to the actual physical distance between RIS elements, allowing efficient redirection of wireless signals and enhancing communication between the transmitter and users even without a direct path. The coordinates of the transmitter and RIS surface are detailed in TABLE II.

TABLE II
Position and Coordinates for Transmitter and RIS

COMPONENT	COORDINATES (X, Y, Z) IN METERS
TRANSMITTER	(0, 0, 20)
RIS SURFACE	(40, 0, 10)

The user positions and coordinates were changed across two different scenarios. The first scenario is presented in Table III, while the second scenario is shown in Table IV.

TABLE III
Position and Coordinates for Users in the First Scenario

COMPONENT	COORDINATES (X, Y, Z) IN METERS
USER 1	(10, 5, 0)
USER 2	(30, 15, 0)
USER 3	(40, 20, 0)

TABLE IV
Position and Coordinates for Users in second Scenario

COMPONENT	COORDINATES (X, Y, Z) IN METERS
USER 1	(15, 35, 3)
USER 2	(30, 10, 6)
USER 3	(35, 5, 9)

V. RESULTS OF SIMULATION

The wireless communication system was simulated based on the assumptions outlined in the model assumptions section. The received signal power was calculated in two cases: using the Reconfigurable Intelligent Surface (RIS) and through the non-line-of-sight (NLOS) path, for the first scenario. These results are illustrated in Figure 3.

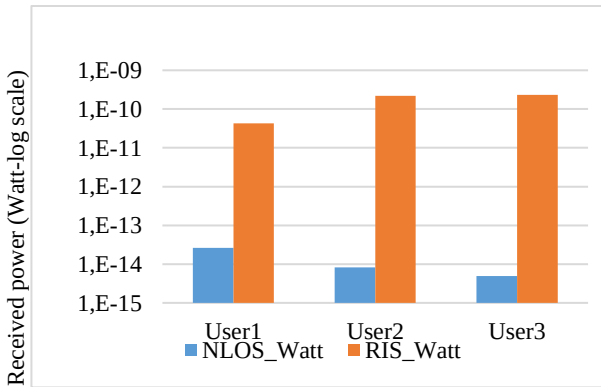


Fig. 3. Comparison of the Received Power via RIS and the NLOS Path.

In the Non Line of Sight (NLOS) scenario, the received power at User 1, who is located closest to the transmitter, was 2.61×10^{-14} watts, which corresponds to approximately -135.8 dB. This value was higher than the received power measured at both User 2 and User 3 under the same NLOS conditions. On the other hand, in the RIS-assisted scenario, User 3, who is positioned nearest to the RIS surface, received a signal power

of 2.34×10^{-10} watts, or about -96.3 dB. This was greater than the power received by both User 1 and User 2 in the same RIS-based configuration. These findings align closely with the theoretical values calculated using equations (1) and (2), and also show good agreement with previous studies cited in Section II of this paper. In environments where Line-of-Sight (LOS) is blocked due to obstacles, the height and orientation of the RIS surface have a significant impact on enhancing received signal strength. This highlights the importance of selecting an appropriate location and elevation for the RIS to achieve optimal performance. Accordingly, this paper proposes a dynamic RIS model that allows flexible adjustment of both the RIS height and its horizontal orientation. The impact of these parameters on received power is evaluated in detail under both Scenarios 1 and 2, based on the following assumptions:

1. Changing the RIS height from 5 to 15 meters.
2. Varying the RIS azimuth angle from 0° to 45° .

The simulation results of the proposed model, under the stated assumptions, confirm that changing the RIS height plays a major role in improving the received signal power, as shown in Figures 4 and 5 for Scenarios 1 and 2, respectively.

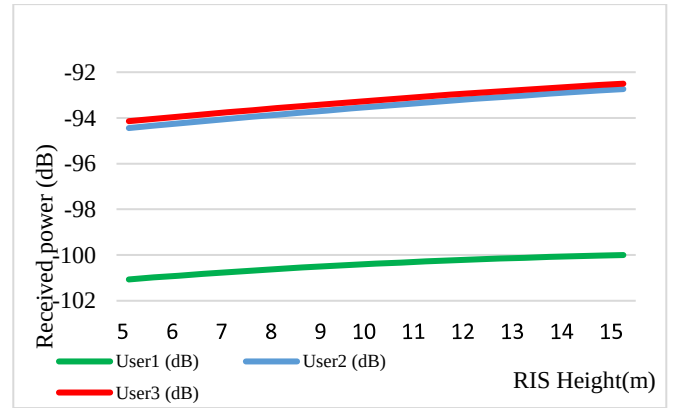


Fig. 4. Impact of RIS Height on the Received Signal for first Scenario.

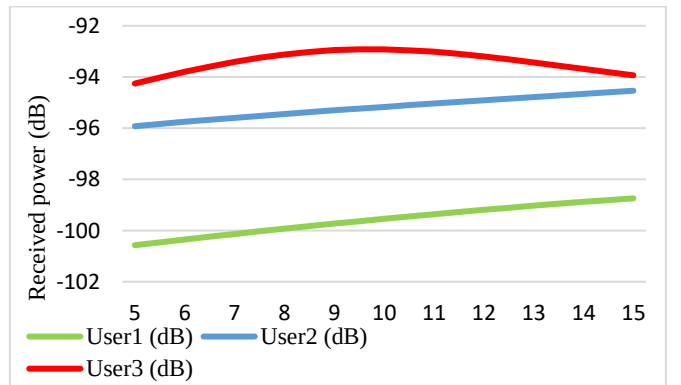


Fig. 5. Impact of RIS Height on the Received Signal for second Scenario.

Figures 4 and 5 shows that User1 receives the lowest reflected signal power from the RIS surface in both scenarios. This is due to his location being the farthest from the reflecting surface compared other users (User2 and User3) in same scenario. It is

also clear where increasing the RIS height improves the received signal, and that because of RIS height getting closer to the height of the transmitter, reducing the distance between them and enhancing the signal strength.

for changing in the RIS azimuth angle, the simulation results for Scenarios 1 and 2, shown in Figures 6 and 7 respectively, indicate that this change has a greater effect on the received signal. This is because the azimuth angle directly affects in the calculation of the incidence and reflection angles, as that was explained in Equation (2).

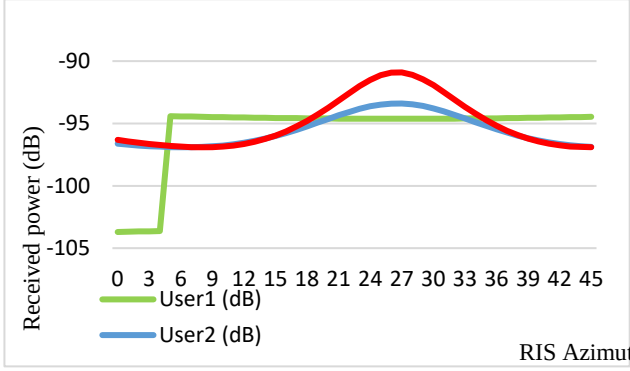


Fig. 6: Impact of RIS Azimuth on the Received Signal for first scenario.

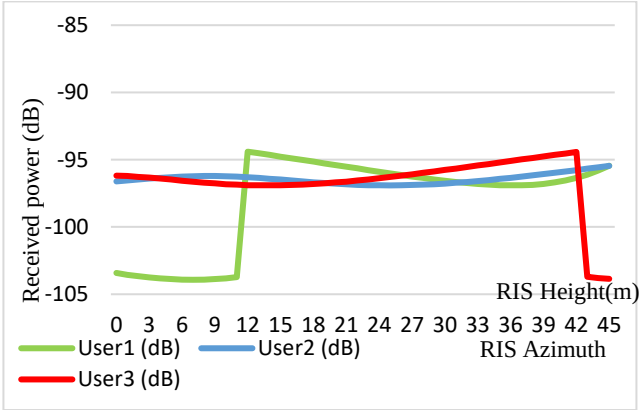
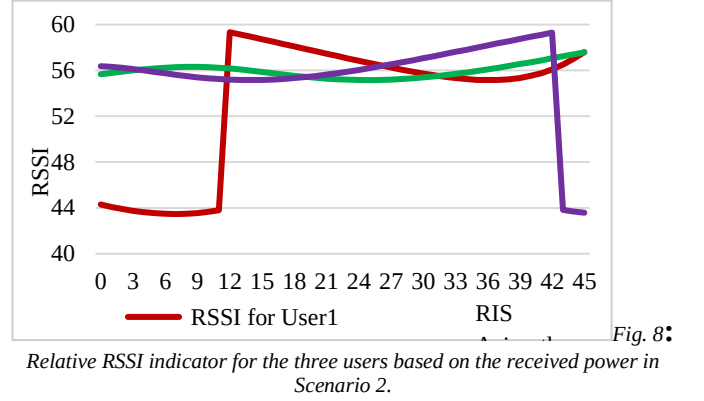


Fig. 7: Impact of RIS Azimuth on the Received Signal for second scenario.

Figures 6 and 7 clearly show the effect of changing the horizontal orientation angle of the RIS on the received signal power. As the orientation angle increases horizontally, a slight change in the received signal was observed at Users 2 and 3. However, User 1 experienced a significant improvement, with the signal power increasing from around -104 dB to -94 dB at a steering angle of 5° in Scenario 1, and 12° along the horizontal path between the transmitter and the RIS. This represents more than an 8-fold increase compared to the fixed RIS case. The optimal steering angle can be considered as 27° for Scenario 1 and 26° for Scenario 2, since the received signal begins to fluctuate after these values. To enhance the realism of the proposed model and align it with modern wireless systems, the received power values shown in Figure (7) were converted into a relative RSSI indicator, as illustrated in Figure (8) and based on Equation (3). It is important to note that this indicator does not represent the actual RSSI values used in commercial devices. Instead, it serves as an applied relative metric derived

by normalizing the simulated power values between the minimum and maximum observed in the simulation results.



This analysis confirms the effectiveness of the dynamic RIS model. Although adjusting the orientation angle may sometimes cause a drop in signal strength for some users, the positive impact in the targeted directions is clear and effective. This supports the idea of using a dynamic RIS that can adjust its height and steering angle based on user distribution or traffic load, directing the energy toward the areas that need it most, and improving the overall network performance. Based on the RSSI indicator, we propose a self-adaptive control model that adjusts the RIS parameters according to the RSSI values reported by users to the base station. This concept can later be extended using artificial intelligence techniques to estimate the optimal steering angle or elevation. The proposed mechanism for dynamically adjusting the RIS steering angle is illustrated in Algorithm 1.

Algorithm 1 Dynamic RIS Azimuth Adjustment Based on RSSI

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- Step 1: Initialize azimuth angle $\Theta = 0^\circ$
 - Step 2: Define $\Theta_{\max} = 90^\circ$, and step size $\Delta\Theta = 1^\circ$
 - Step 3: For each θ in $[0, \Theta_{\max}]$ with increment $\Delta\Theta$:
 - Update the RIS angle to Θ
 - For each user:
 - Measure the RSSI at current Θ
 - Store the RSSI value
 - Step 4: For each user:
 - Find the Θ_{opt} that gives the maximum RSSI
 - Step 5: Use Θ_{opt} as the optimal steering direction for RIS
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This algorithm defines a simple iterative process to determine the optimal azimuth angle of the RIS based on maximizing the Received Signal Strength Indicator (RSSI) from each user. It has been implemented in MATLAB to guide beam steering dynamically in the simulated scenarios.

VI. CONCLUSION

In this study, a new model for a Reconfigurable Intelligent Surface (RIS) was proposed, where both the height and the horizontal angle (azimuth) can be dynamically changed to enhance the received signal power in environments that lack for line-of-sight (NLOS). The simulation results showed that changing the position and direction for the RIS helps improve signal quality, especially for users that located near the reflection direction.

In the simulated scenarios, it was observed that changing the azimuth angle increased the received signal power for User 1 from -104 dB to -94 dB, which equals more than 8 times the power received in the fixed RIS case. Changing the surface height also led to a noticeable improvement in the received signal, which proves that the dynamic model offers greater flexibility to adapt to environmental changes.

It is worth noting that directing the RIS surface Towards the direction of users will improve the received signal power. This highlights the importance of using an adaptive approach, especially in environments where user distribution or traffic load changes frequently. With this approach, the signal can be intelligently and efficiently directed to the areas that need it most, making this solution suitable for meeting the demands of sixth-generation (6G) networks, which require high performance and flexible responsiveness as needed.

In addition, RSSI indicators offer a direct way to evaluate network performance and enable the development of adaptive control mechanisms based on this feedback. It also can work with integration AI techniques with these models to determine the optimal RIS height and azimuth angle.

VII. SUGGESTIONS AND FUTURE WORKS

Based on the findings of this study, the proposed dynamic RIS design demonstrates strong potential for enhancing the performance of wireless networks, especially in environments with varying user distributions. To further improve and extend this model in future research, the following directions are suggested:

1. Develop a practical implementation of the proposed model and conduct real-world testing to validate and compare the simulation results.
2. Incorporate artificial intelligence techniques to enable automatic adjustment of the RIS height and orientation based on user locations and traffic demand.
3. Investigate the impact of vertical tilt (elevation angle) of the RIS on signal performance.
4. Integrate realistic environmental effects such as interference, shadowing, and user mobility to build a more comprehensive and practical simulation model.
5. Developing an intelligent control model capable of predicting the optimal mechanical configurations of the RIS based on RSSI, SNR, and CQI indicators.

These studies provide new research opportunities in intelligent wireless communication systems, particularly in dynamic control for RIS. By using feedback indicators such as RSSI, SNR, and CQI, the researchers may be developed adaptive RIS algorithms that respond to users' mobility. Future research could also join RIS control with AI techniques to optimize mechanical variables like height, horizontal azimuth angle, or even the surface area of the RIS itself. That research would contribute to building more flexible and efficient communication systems and capable of meeting the complex demands of 6G environments.

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