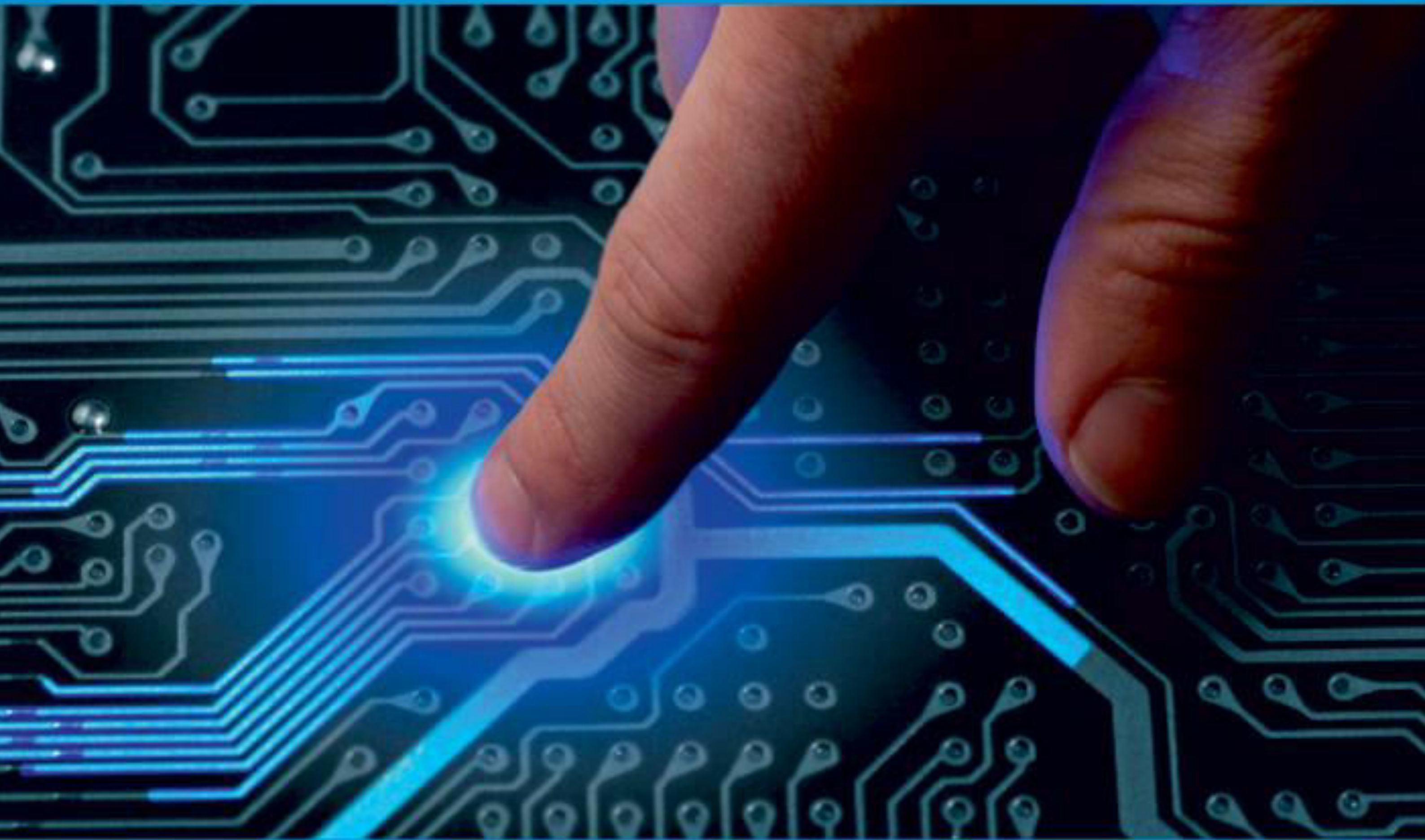
IJIRCCE

e-ISSN: 2320-9801 | p-ISSN: 2320-9798



INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN COMPUTER & COMMUNICATION ENGINEERING

Volume 11, Issue 4, April 2023

INTERNATIONAL STANDARD SERIAL NUMBER INDIA

Impact Factor: 8.379

| e-ISSN: 2320-9801, p-ISSN: 2320-9798| www.ijircce.com | |Impact Factor: 8.379 |

|| Volume 11, Issue 4, April 2023 ||

| DOI: 10.15680/IJIRCCE.2023.1104061 |

Performance Analysis of Reconfigurable Intelligent Surface in Wireless Communication

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ABSTRACT: Wireless communication systems are facing increasing demand for higher data rates, better coverage, and improved energy efficiency. Reconfigurable Intelligent Surfaces (RIS) are a promising technology that can help to address these challenges. RIS are planar arrays of passive elements that can be used to control and manipulate the electromagnetic waves in wireless communication systems. Provides an overview of RIS technology, including the principles of operation, design considerations. Discuss the advantages of RIS over other technologies and discuss the challenges and future research directions for RIS in wireless communication systems.

KEYWORDS: Antenna Arrays, Channel capacity, Reconfigurable, Propagation.

I. INTRODUCTION

Wireless communication systems have become an integral part of modern society, connecting people and devices across the globe. However, as the demand for wireless data continues to grow, the limitations of existing wireless technologies have become more apparent. To address these challenges, Reconfigurable Intelligent Surfaces (RIS) have emerged as a promising technology for improving wireless communication. RIS are planar arrays of passive elements that can reflect and manipulate electromagnetic waves, enabling advanced signal processing and beamforming capabilities. Unlike other wireless technologies, RIS are inexpensive, power-efficient, and can be easily integrated into existing wireless networks. Furthermore, the use of RIS has the potential to enhance coverage, increase network capacity, and reduce interference in wireless communication systems.

Moreover, RIS technology has several advantages over traditional wireless technologies such as antennas and relays. RIS can be easily integrated into existing wireless networks and can be deployed in a wide range of environments, including indoor and outdoor settings. Additionally, RIS are highly customizable, allowing for the creation of tailored solutions that can address specific wireless communication challenges. These advantages, coupled with the recent advancements in RIS research, have led to a surge of interest in this technology among researchers and practitioners alike.

In this paper, we aim to provide a comprehensive overview of RIS technology, highlighting its advantages, challenges, and potential applications in wireless communication. We review the state-of-the-art research on RIS and provide a roadmap for future research in this field. Our hope is that this paper will inspire further research and development of RIS technology, leading to a new era of high-performance and energy-efficient wireless communication systems.

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II. FUNDAMENTALS OF RIS

Reconfigurable Intelligent Surfaces (RIS) are a recent breakthrough in wireless communication technology that have the potential to significantly enhance the performance and efficiency of wireless communication systems. RIS refers to a surface that can adaptively control the electromagnetic waves that pass through it, by manipulating the phase, amplitude, and polarization of the waves.

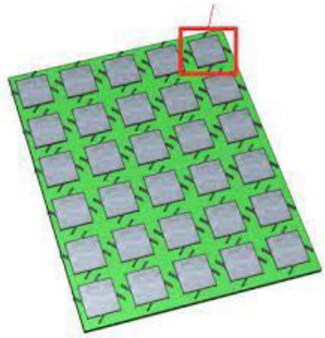

Fig 1: Reconfigurable Intelligent Surface

The idea of RIS has its roots in the concept of metamaterials, which are artificial materials that can manipulate electromagnetic waves in unconventional ways. However, RIS takes the idea of metamaterials a step further by using a large number of small, reconfigurable units that can be controlled independently to create a surface that can adaptively control electromagnetic waves.

The fundamental idea behind RIS is to use many small, reconfigurable units that can be controlled to manipulate the electromagnetic waves that pass through them. Each unit can be programmed to change the phase and amplitude of the wave, which can be used to steer the wave in a specific direction or focus it on a particular point. By controlling the phase and amplitude of each unit, the overall behavior of the surface can be controlled to achieve specific communication goals, such as improving signal strength, reducing interference, and enhancing security.

III. ANALYZING RIS ELEMENT BEHAVIOR THROUGH CIRCUIT MODEL

Let us delve into the behaviour of the Reconfigurable Intelligent Surface (RIS) when it is exposed to electromagnetic waves. For a better understanding, let's examine the processing of incident signals by one of the RIS elements. We can analyse the behaviour of an RIS element by considering its equivalent circuit.

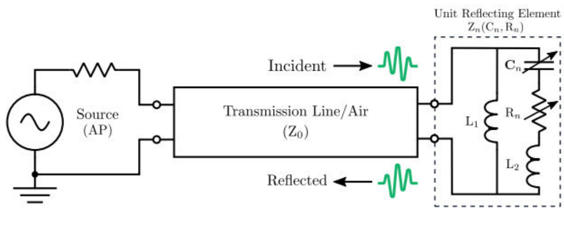

Fig 2: Equivalent Circuit of RIS Element

As we cannot directly control the properties of the wireless propagation medium, we aim to manipulate the characteristics of the signal within the medium. This can be achieved by adjusting certain parameters on the RIS, allowing us to exert greater control over the wireless medium.

The metallic parts of a reflecting element can be represented by inductors, as high-frequency currents generate a quasi-static magnetic field. The equivalent circuit model for the n-th reflecting element, shown in Figure 2, can be represented as a parallel resonant circuit, with its impedance determined by

$$z_n(c_n, R_n) = \frac{j\omega L_1\left(j\omega L_2 + \frac{1}{j\omega c_n} + R_n\right)}{j\omega L_1 + \left(jwL_2 + \frac{1}{j\omega c_n} + R_n\right)} \quad (1)$$

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Where z_n is the impedence of the element produced and c_n and R_n is the effective capacitance and resistance of the element. L_1, L_2 are the inductance of the metal sheets present in the RIS element and ω is the angular frequency of the element.

From the Equivalent circuit analysis, the reflection coefficient of the RIS element is derived as follows.
Let us assume v_n is the Reflection coefficient of the nth element in RIS. It is written as

$$v_n = \frac{z_n(c_n,R_n)-z_0}{z_n(c_n,R_n)+z_0} \quad (2)$$

So, the v_n is depends on the c_n and R_n. Then to illustrate this we can vary the capacitance and observe how the reflection coefficient is varied. From this we give observations of how the amplitude and phase of the incident signal is varied when we vary the capacitance of the RIS element.
Let us assume L_1 = 2.5e-9, L_2 = 0.7e-9 and R_n =1

Free space impedance (z_0) = 377 and plot the results by varying the c_n. Take c_n values as 0.79,0.88,0.96,2.2 pF. The result for phase response is calculated as Angle (v_n) and for the Amplitude is abs (v_n).

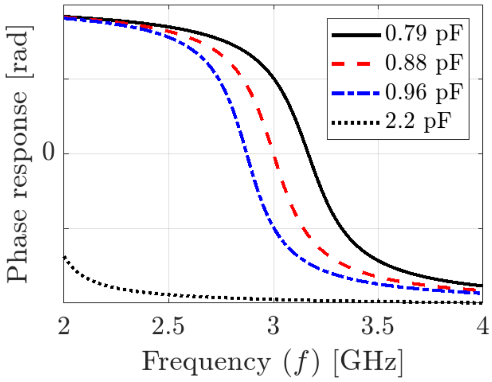

Fig 3:Phase Response of RIS Element

The plot is drawn between the Phase response of the from the reflection coefficient vs frequency for the different capacitance values. Here we can observe the Phase variations for the different capacitance values.

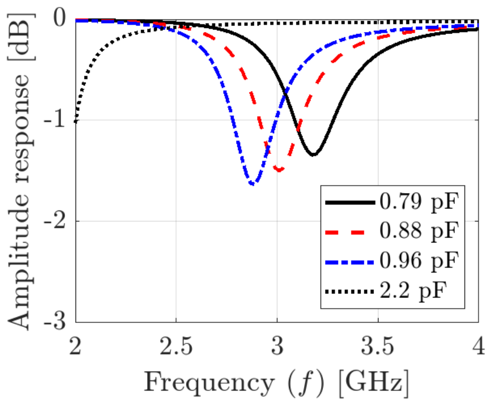

Fig 4: Amplitude Response of RIS Element

The plot drawn is between the Amplitude response vs frequency for different capacitance values. Here also we can observe the variations in the Amplitude when varying the capacitance of the RIS element.

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IV. SYSTEM MODEL

The end-to-end model describes how different components of the wireless system, such as the transmitters, receivers, RIS, and channels, are connected and interact with each other.

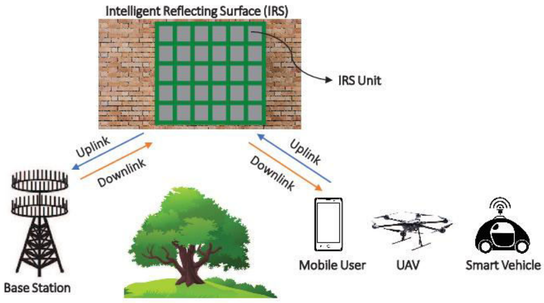

Fig. 5: An RIS in wireless communication

Weareconsidering a wireless communication system that deploys an RIS consisting of N reflecting elements to assist in transmitting signals from a Base Station (BS), as shown in Figure 2. The programmable RIS reflecting elements can be optimized through an RIS controller. Additionally, the RIS controller establishes a separate wireless link to communicate with the BS, allowing for efficient control of the RIS reflection. It is assumed that signals reflected by the RIS more than once have negligible power due to path loss. Moreover, we adopt a quasi-static flat-fading model, which assumes that all wireless channels remain constant throughouttransmission block.

Let us assume there is a two paths between the BS and the end user. One is a direct link and the other one is through the RIS. Assume the propagation losses as -80dBm from the BS to the RIS and -60dBm from the RIS to the User. This is the one path and other one is direct path which has the two cases.

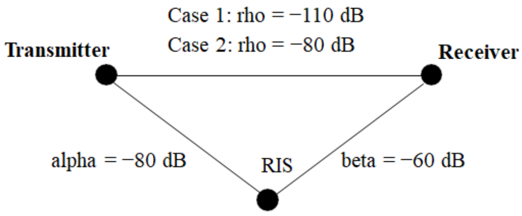

Fig 6: Paths between user and BS

One is weaker strength -110dBm and other one is -80dBm good strength. The user gets better rates in the line-of-sight with BS when the signal strength is good i.e. -80dBm. When the signal strength is weak i.e. -110dBm the direct link is not good, so the user gets better rates when the signal travels through the RIS. Let us consider the parameters as Bandwidth is 1MHZ with the varying no. of elements. And RIS-controlled path is 30dBm weaker than the direct path between the user and the BS.

The SNR value is calculated using the below formula.

$$SNR = \frac{P}{BN_0}\left(\sqrt{\rho} + \sum_{n=1}^{N}\sqrt{\alpha_n\beta_n\gamma}\right)^2 \quad (3)$$

Using SNR, the capacity of the user can be derived. Thet is given as

$$\text{Capacity} = B * \log_2(1+ SNR) \quad (4)$$

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Where SNR is the Signal to Noise Ratio, P is the Power transmitted and
α = BS To RIS Propagation loss
β = RIS To User Propagation loss
ρ_1 = Signal at user equipment in case1
ρ_2 = Signal at user equipment in case2
γ= 1(Loss in RIS)

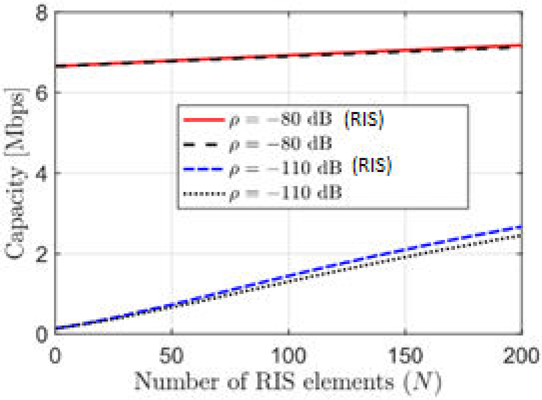

Fig 7: Capacity vs Number of elements

The graph plot between the Capacity and Number of RIS elements. Here we conclude that when the direct link is weaker than the advantages of RIS is enable. It can outperform over the direct path; we can see some throughput is change at the -110dBm in the capacity of the user when using direct path and the RIS-controlled path. RIS-Controlled path is getting more capacity than the Direct path.

V. DESIGN CONSIDERATION

To design an effective RIS, several key considerations need to be addressed. First, the placement and orientation of the RIS should be optimized to achieve the desired coverage and capacity. The location and orientation of the RIS can significantly impact the reflected signal quality, interference, and multipath propagation. Second, material selection is critical for reflection efficiency, compactness, and low loss. The reflective elements should be made of low-cost materials with a high reflection coefficient, such as metal or graphene. Third, the size and shape of the RIS elements should be optimized for the desired reflection pattern and bandwidth. The element size should be smaller than the wavelength of the signal to avoid diffraction effects. Fourth, the phase shift of each element in the RIS should be controllable to achieve the desired reflection pattern. Finally, the RIS should consume minimal power and be compatible with existing wireless communication standards.

Designing an effective RIS requires careful consideration of placement and orientation, material selection, size and shape, phase control, power consumption, signal processing, and compatibility. Optimizing these factors can help achieve the desired performance improvements in wireless communication networks. With the potential to enhance wireless network coverage, capacity, and energy efficiency, RIS can play a crucial role in future wireless communication systems.

VI. CHALLENGES WITH RIS

Here are some challenges associated with RIS:

1. Complexity of design: The design of RIS is complex and requires careful consideration of several factors, such as placement and orientation, material selection, and size and shape optimization.
2. Interference and scattering: RIS can cause interference and scattering of signals if not designed properly, which can result in signal degradation and reduced system performance.

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3. Limited bandwidth: RIS operates within a limited bandwidth, which can restrict the achievable data rates and coverage area.
4. Signal processing complexity: The signal processing requirements for RIS-based communication systems can be complex.
5. Sensitivity to location and environment: The effectiveness of RIS can be highly dependent on the location and environment.

These challenges highlight the need for further research and development to address the design complexities and performance limitations of RIS in wireless communication networks.

VII. CONCLUSION

In conclusion, reflecting surfaces (RIS) are a promising technology for improving wireless communication networks. The phase and amplitude response of RIS by varying the capacitance. The performance of RIS depends on several design factors, including the number of elements, placement and orientation, material selection, size and shape optimization, and controllable phase shift. As the number of elements in the RIS increases, the complexity of the design and signal processing also increases, which can impact the system's performance.

Overall, the performance of RIS in wireless communication networks is a topic of ongoing research and development. As this technology continues to evolve, it is essential to consider the trade-offs between performance and complexity, as well as the challenges associated with deploying and maintaining RIS in real-world scenarios. With further advancements, RIS can help address the growing demand for high-speed and reliable wireless communication networks.

ACKNOWLEDGEMENT

It is privilege to express our deepest gratitude to our college management, Gayatri Vidya Parishad College for Degree,and PG Courses (Autonomous) for extending their utmost support and cooperation in providing all the provisions for successful completion of our project.

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