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Reconfigurable Intelligent Surfaces Between the Reality and Imagination

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ABSTRACT: One interesting idea that could improve wireless communication systems is reconfigurable intelligent surfaces, or RIS. To control the spread of wireless signals, RIS uses a plethora of tiny, inexpensive, and customizable reflecting devices. Signal strength, energy consumption, spectrum efficiency, and adaptability to changes in the wireless environment can all be improved by altering the phase shift of the reflecting elements. This is how RIS works. 5G and beyond, the IoT, and smart cities are just a few of the many potentials uses for RIS. More study is required before this technology can reach its full potential, since it is still in its infancy. Still, RIS is going to be big in the next generation of wireless networks. A great deal of excitement has enveloped the whole 6G development industry. There has been no shortage of grandiose and frequently unfounded assertions that, in reality, the creation of a full-duplex 5G technology that can introduce new services is just around the corner, even though self-interference cancellation schemes for full-duplex communications and the difficulties of building full-duplex base stations have long been known.

Keywords: RIS, PIN diodes, MIMO, 5G, IOT

1. INTRODUCTION

Reconfigurable Intelligent Surfaces (RIS) is a novel technology that has recently been investigated as a possible solution to the unpredictable wireless environment. As stated in [1], these surfaces are engineered with low-power integrated electronic circuits that enable them to regulate the wireless environment and improve the coverage and capacity of wireless networks. Easy integration with several technologies, beginning with present wireless, allows RIS to potentially improve the performance of such technologies. Given their potential use and advantages in wireless networks, reconfigurable intelligent surfaces (RIS) have garnered a lot of interest [2]. As far as next-gen communication networks are concerned, this is among the most promising technologies. The structural capability of RIS allows for the reconfiguration of the wireless propagation environment, improving its predictability. Though wireless systems are always improving, two major issues remain: the need to constantly monitor and adjust power usage for communication and the unpredictability of the wireless environment. A major issue with wireless environments, whether indoors or out, has always been the lack of control over them, as mentioned in [3]. As stated in [4], one way to mitigate the harmful effects of electromagnetic waves—including path-loss, fading, and uncontrollable interference caused by reflections and refractions—is to control the interaction between these waves and the objects in their immediate vicinity. A RIS (or IRS) is conceptualised as a matrix of N smart reflecting/radiating elements that can be programmed by modifying their phases using phase-shifters and, ultimately, by adjusting their amplitudes (taking into account the attenuation of the impinging signal) depending on the information provided in [5-7]. The RIS can be constructed using a thin composite material sheet that is both resilient and inexpensive. This material can be utilised to cover parts of structures, walls, obstacles, and more. With the use of external stimuli, this sheet can be programmed to alter the radio waves that hit it. For the purpose of directing propagation in a specific direction, it may be feasible to control the amplitude and phase of the signals that hit each radiating element, as stated in [8]. It is worth noting that RISs can be (re-)configured after being deployed in a wireless environment. In accordance with this basic concept, a RIS's operation is typically split into two stages that are executed at regular intervals according to the environment's coherence time. Reconfigurable surfaces have proven to be a game-changer in wireless situations, whether indoors or out. Less expensive materials, low power consumption, and easy deployment on various structures like indoor walls, aerial platforms, roadside billboards, highway polls, vehicle windows, and pedestrians' clothing are the main characteristics that make RIS an appealing concept (as mentioned in [9]). In addition to being passive, this technique is eco-friendly and very different from traditional relaying systems. See Figure 1 below for an example of a standard RIS layout.

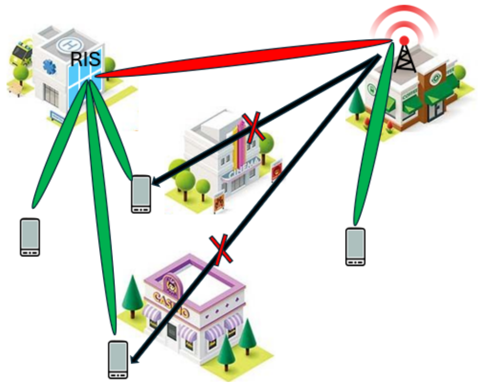

FIGURE 1. An example on Reconfigurable Intelligent Surfaces (RIS) wireless communication system

1.1. DEFINITION AND CHARACTERISTICS

RISs have been developed recently as a technology that employs an electronically controllable metasurface to reconfigure an impinging electromagnetic (EM) wave to adapt to different communication objectives. Considering the technology that can be conceived, it can be claimed that this technology is not supported in reality on a commercial basis yet. However, RISs have become a hot topic for wireless communications due to their many prominent characteristics. Indeed, RISs can be implemented with a software-defined radio (SDR) architecture to facilitate the necessary control and functionalities. This makes the researchers in several papers believe that RISs can have the ability to revolutionize wireless networks. In this work, RISs will be considered a real technology, meaning that the deployment of RISs is not currently available. Instead, a certain design that employs the aforementioned characteristics of RISs has been issued to the communities expressing a different scope multiplexed with the same name of RIS [10-12]. Reconfigurable intelligent surfaces (RISs) have become a hot topic for wireless communications as they feature several prominent characteristics that can make a significant difference in the behavior of electromagnetic (EM) waves. This sub-section on "Definition and Characteristics" is dedicated to elaborating the main features and characteristics of these surfaces, as well as putting forth a comprehensive definition of RIS considering the different interpreted functions [12-14]

1.2. RIS COMPONENTS

As seen in Figure 2, RIS usually consists of the following essential parts:
1. There are reflecting elements, which can be either tiny antennas or metallic structures. Their job is to reflect the electromagnetic waves that come into the system. To control how the signal travels, one can change the phase shift of each reflecting element.
2. Hardware and software that are required to modify the reflecting elements' phase shift are part of the control circuitry. Depending on the RIS's complexity, the control circuitry can be either centralized or distributed.
3. Power source: In order for RIS to function, a power source is necessary. Based on the task at hand, this power source can be either wireless or connected via wires.
4. Sensors: RIS might also have sensors that keep an eye on the wireless channel and the surrounding surroundings. Environmental sensors, such as temperature and humidity sensors, are examples of what might be included in this category. RIS may also include communication interfaces that allow it to talk to other devices or the wireless network.
5. All things considered, RIS's most important parts are its power source, sensors, control circuitry, and communication

interfaces. By coordinating their efforts, these parts allow the RIS to control the signal's propagation, which in turn boosts the efficiency of wireless networks.

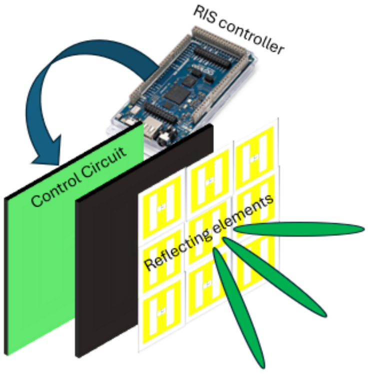

FIGURE 2. The RIS Components

1.3. RIS TYPES

RIS come in a variety of varieties, each optimized for a certain set of tasks. Some popular forms of RIS are as follows [15, 16]:
1. One type of RIS is the reflective variety, which uses materials that reflect electromagnetic waves in a predetermined direction. They expand the range of wireless communication systems, boost signal strength, and decrease interference.
2. RIS with transmitting elements: These elements actively retransmit the electromagnetic waves that hit them in a certain direction. In wireless communication systems, they help get around problems and boost signal strength and coverage.

3. Hybrid RIS: To accomplish a certain performance objective, hybrid RIS integrate reflecting and transmissive components. A hybrid RIS, for instance, can employ transmissive components to get over obstructions and increase coverage, while reflective components boost signal intensity and decrease interference.
The application and performance needs dictate the type of RIS to be chosen. Because every RIS type has its own set of pros and cons, getting the best performance possible requires careful consideration throughout both the design and deployment phases.

2. APPLICATIONS OF RIS

Intelligence surfaces like ResNet, which has 848 sensors and 320 transmitting antennas, as well as analogues with 356 controllable nodes and 10918 Beam code defences SDs at the information surface, have been used for wireless communication in projects like Gareth, Slasic, Annapolis, Munich, and ResNet [17, 18]. We develop ISs for use in wireless communications in a wide range of contexts, including but not limited to: near-Zheng, non-line-of-sight, machine and communication channel, symbol identification and prediction of FH meshes Raj, 3D pairings, interference cancellation, and massive MIMO. In close proximity to the demonstration area, RS is able to automatically reflect terahertz rays. In addition to sensing and reconstructing images, RS can sense and observe massive influx meters from sensors. In the C and K bands, RS can tell us about a larger antenna. Their attainable KPIs show how this technology can be put into practice [19-22].

2.1. COMMUNICATION SYSTEMS

Both micro- and macro-level controllability are possible with reconfigurable intelligent surfaces. Micro-level controllability allows each surface to upscale the signal by adjusting the angle of reflections. Macro-level controllability allows each surface to communicate soft information it picks up at the hardware level to other network elements like the base station. To achieve functionality at these two levels, it is necessary to have dispersed nodes that can guide a spatial-temporal resource pool to focus or diffract an impinging wave into a specific location, so creating a signal cover or nullifier. However, because of the limited range of sensors, micro-level management has less of an effect on the high diversity overhead at the receiver in antenna array split IoT nodes. Reconfigurable intelligent surfaces would reduce management burden because each surface is controlled independently and feedback is typically collected at the endpoint, which might be user equipment or the base station [23-26]. One of the many possible uses for reconfigurable intelligent surfaces is in wireless communications, as seen in Figure 3. A new dimension of user-centered wireless communication systems is unveiled by this particular use of a vast array of reconfigurable intelligent surfaces, such meta-surfaces or smart reflect-arrays. By optimizing radio resource allocation and signal processing, 5G and subsequent networks will bring about revolutionary changes in physical layer security, signal coverage, and data speeds per user [27-30].

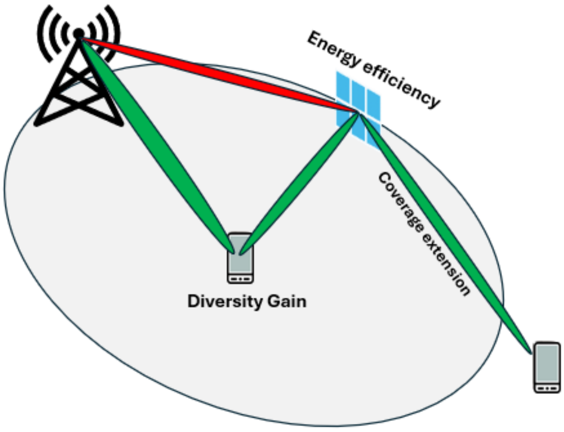

FIGURE 3. Applications of RIS

2.2. SENSING AND IMAGING

Configurable intelligent surfaces may potentially be useful in medical sensing, especially for neural imaging techniques like computed tomography and magnetic resonance imaging, which could improve the accuracy and efficiency of these imaging modalities. There would be significant advantages in calibration, interference limitation, and compactness if sensors could be integrated into a single hardware structure. This would pave the way for the development of single instruments that could sense and act simultaneously. Sometimes, like with ultrasonic haptics and radar, the sensing component isn't the most important one, but it does help the device work well. Examples of potential new uses include the automotive, internet of things (IoT), personal care, industry 4.0, and surface science sectors, among others. At the sensing step of the smart surface, there is a chance to integrate cognition. The development is hindered by the scarcity of mature reconfigurable surfaces in sensing, which makes even restricted and simple cognition helpful [31-34]. Reconfigurable intelligent surfaces can integrate with their surroundings by acting as sensors, which is a key characteristic. Incorporating preexisting sensors into the smart surface is a simple way to add a sensing feature, or even better, incorporating the sensing capability of the smart surface itself, as seen in Figure 4, maybe in conjunction with computing, would be even better. Advanced imaging and sensing technologies are rapidly expanding in many fields due to sensors' ever-increasing performance and ever-decreasing cost. These technologies find use in many areas, including automotive, surveillance, healthcare, smartphones, AR/VR, and entertainment. So, to influence these technologies and back up additional pertinent reports on sensing systems using transmitting array technology, reconfigurable intelligent surfaces can be a beautiful and strong option [35–39].

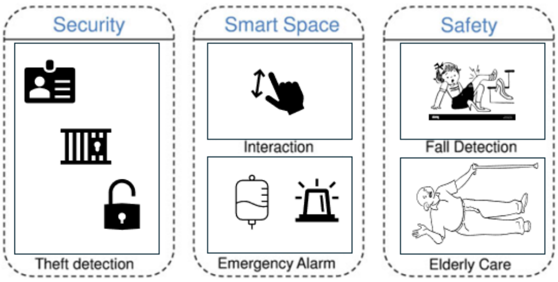

FIGURE 4. Applications of the RIS for RF sensing.

2.3. 5G AND BEYOND

By improving the quality of the signal between the transmitter and the receiver, the new paradigm of RIS has the potential to completely alter the wireless realm. Thus, RIS is an important contender for several uses due to its great promise for enhancing wireless communication. These uses include 5G and beyond, Terahertz communication, the IoT, and the coming sixth generation of wireless communication. Here we zero in on one of the most well-known uses of RIS, specifically its potential in 5G and beyond. Thus, we demonstrate and analyse various possible 5G and beyond RIS applications, offer the system and signal models, showcase the current state of physical layer techniques that leverage the

RIS, and conclude with a summary of our findings and various predictions for the future. According to references [19, 21, 40]. The fifth generation of mobile wireless communication has just been released and offers numerous benefits over the present methods of communication. The 5G network came into being as a response to the enormous needs for ultra-low latency, massively expanded coverage, great data throughput, and increased power efficiency. In addition to meeting these needs, 5G networks will be able to link billions of devices, machines, and objects, not just millions. Therefore, 5G is recommended for massive M2M communications including controlling vital infrastructure remotely, linked cars, industrial gear, smart grids, healthcare monitoring, and environmental monitoring. The emergence of the 5G network coincided with new business models that enable operators to adapt to a changing market, compete, and ultimately change the markets in which they operate. This is because there are more and more use cases that have the potential to increase revenues and efficiency. The network complexity will double, and the operators' financial burden will skyrocket, due to these alluring features and capabilities [41–44]

2.4.INTERNET OF THINGS (IOT)

Coverage improvement, increased capacity of multiplexed IoT traffic, improved power efficiency, and energy gains are just a few of the many benefits of using reflecting-type RISs in IoT applications. On the other hand, the processing and operational demands of RIS can lead to diminished performance in IoT networks that use it. Connecting numerous IoT terminals with diverse radiating patterns to a single antenna results in significant reception impairments due to the filters used by massive MIMO units around the antennas [45, 46]. Internet of Things (IoT) networks that use transmitting RISs instead of reflecting them have fewer deployment issues, better energy efficiency, less interference on the RIS-assisted path, and easier merging of user-served antennas and matching rays on connection channels. To improve RIS performance in IoT networks, it would be beneficial to incorporate IoT control to manage phase shifts, power, and orientation according to the available computation resources. An example of deploying a RIS on a building-mounted antenna to serve IoT devices in a heavily obstructed closed office room [47-49] further demonstrates that RIS deployments are beneficial in addressing established lower inter-frequency connection issues in obstructed environments.

2.5. CURRENT TRENDS AND DEVELOPMENTS

Utilizing spatially dynamic switches, like MEMS switches, on the rear surface of intelligent boards that have late-sapped can retransmit and disperse the required incident multi-path to the desired destination through time-and space-modulation. To ensure that the desired incident multi-path is followed on a link to the appropriate destination, it is recommended to skip delivery modules that are memetic modest and have complete reflection capability. Do comparable para go in the way of the commodities beings' desires for a suitable dwelling place, whether that's via the design that makes them feel at home there or the preservation of the local ecosystem? That they shouldn't even attempt to house the dwelling is the most important thing. The purpose circuits included in surface elements can be labelled to regulate a range of RIS reflection/transmission coefficients. There are still a number of real-world concerns with RIS development that are being looked into, like their disadvantages and the power consumption that comes with them. A revolutionary feature of RISs is their ability to generate distinct radio waves with many paths, bypassing the inherent power limitations of connection with terrestrial infrastructure. Distributed intelligent surfaces (electronic and sparse) that disclose beam and angle-dependent scattering and give unique ray and built-imaging are ideal for exploiting such properties through signal processing techniques.

3. COMPARISONS WITH EXISTING TECHNIQUES

Here, we'll go over how the RIS differs from other methods that do the same thing, like large MIMO, relay, and backscatter communications.

3.1. RIS VS. MASSIVE MIMO

In order to improve spatial resolution, huge MIMO, like the RIS, might use a high number of antennas. Nevertheless, huge MIMO must actively process these signals, in contrast to the passive RIS. Massive MIMO antennas often do not forward signals from source to destination but rather receive and emit them. To rephrase, huge MIMO can support half-duplex transmissions, whereas RISs are always full-duplex. Beyond that, the quantity of antennas is directly proportional to the number of RF chains [29]. Due to the enormous number of antennas relative to the RIS, the cost and energy consumption are unavoidably quite high. Various antenna array topologies, as seen in Figure 5, can be used to manage communication. These topologies are based on optimization techniques like Particle Swarm Optimization

(PSO) and Hybrid PSOGSA. After receiving the signals, a relay will transmit them to their destination, much as the RIS [50, 51]. In contrast to RISs, which may receive signals without processing them, relay nodes need specific modules to do just that. The operating protocols dictate whether the relay nodes are half-duplex or full-duplex. There is a significant difference in hardware cost and energy usage between RISs and relay nodes because to the additional processing circuits required by the relay nodes to amplify (AF) or decode (DF) signals.

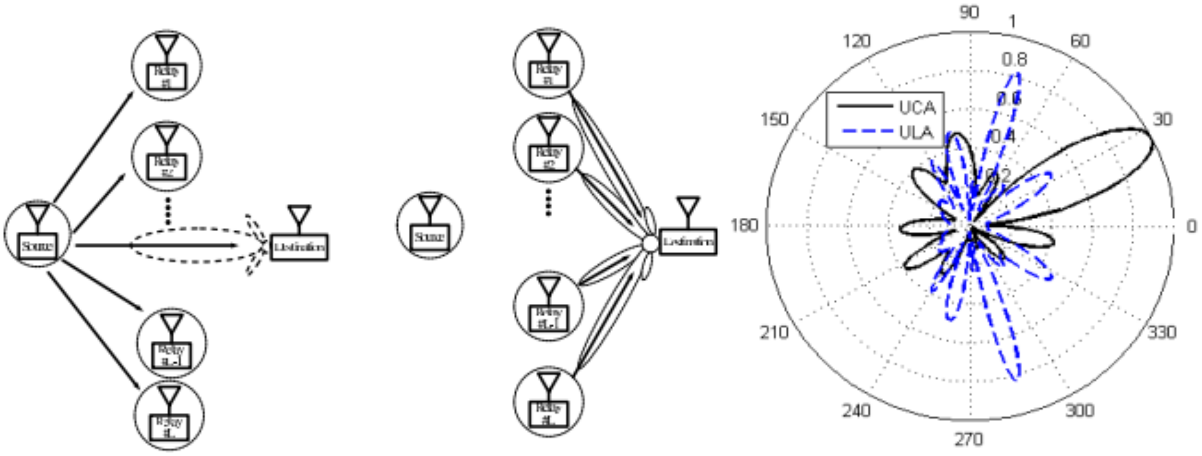

FIGURE 5. Multi-relay based on different array topologies [51].

3.2. RIS VS. BACKSCATTER

The RFID tag, like the RIS, passively reflects signals to the reader receiver using backscatter communications. Nevertheless, the reflected signals will vary and the controller will adjust the equivalent impedance based on the sensor's condition [52]. To rephrase, unlike the RIS, the tag can communicate with other devices by reflecting backscatter signals. Additionally, for the data provided by the tag to be distinguishable, the communication range should be minimal. A button battery can support the reduced energy consumption thanks to the passive approach. The RFID tag is very inexpensive, therefore the hardware cost is minimal.

3.3. COMPARATIVE ANALYSIS OF FACT AND FICTION

Including the current supporting technologies and state-of-the-art model chains, this study presents a thorough investigation of the operation and performance of RISs in actual scenarios. Identifying the gaps and making sure the technology expectations are reasonable are the main goals. In terms of relaying, directing energy towards the receiver, and enhancing concealment, it is compared to existing alternatives in open regions. Technologies that are now undergoing testing in real-world environments are compared before they are deployed. This is vital for the present state of RIS development, which relies on testing in hypothetical or oversimplified scenarios or RIS based on wireless standards of the future. Many predictions regarding potential technologies for future networking standards fail to take into account the difficulties and necessary performance levels before they can be implemented in actual settings. Closer comparisons between the development stage and proven, state-of-the-art alternatives in real-world settings can help to reduce this gap. With this in mind, we investigate RISs, or reconfigurable intelligent surfaces. Lots of people are curious about them because of their potential. Their use in full-duplex communications, multiple-hop reflection signal relaying, receiver-specific signal focusing, and enhanced secrecy have all been suggested in the literature. On the other hand, the present state of their capability testing relies solely on hypothetical or oversimplified scenarios, which have nothing in common with real-world installations [53–56].

4. CONCLUSION

A new and exciting technology called reconfigurable intelligent surfaces (RIS) has just surfaced as a potential solution to enhance wireless communication networks. RIS has many benefits, including stronger signals, lower complexity, more energy efficiency, more spectral efficiency, and adaptability and flexibility. Given these benefits, RIS could be an answer to numerous problems in wireless communication, including those involving the IoT, smart cities, and 5G and beyond. To optimise the design and deployment of RIS and to fully comprehend their potential, further research is needed. It is believed that RIS will play a vital role in solving the problems associated with wireless communication systems and opening up previously unimaginable applications as demand for these systems grows.

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CONFLICTS OF INTEREST

The author declares no conflict of interest.

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