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Reconfigurable Intelligent Surfaces: A Brief Review on Design Specifications

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***Abstract*—The reconfigurable intelligent surface (RIS) is a key technology for sixth-generation (6G) mobile networks. RIS consists of small, low-cost reflecting elements that can be dynamically adjusted using a programmable controller. Each of these elements can efficiently reflect a phase-shifted version of the incident electromagnetic wave. This study presents a brief review of the design specifications of RISs. An overview of the general properties and evaluation parameters is presented. A comparison between passive and active RISs is included. Design specifications and suitable materials are highlighted. Finally, crucial issues for deploying RISs in higher frequency ranges are discussed.**

***Index Terms*—Reconfigurable Intelligent Surface, evaluation parameters, active RIS, passive RIS, sub-THz RIS, 6G**

I. INTRODUCTION

Reconfigurable intelligent surfaces (RISs) are cutting-edge technology that combines wireless communication, electromagnetic information, meta-materials, and other multidisciplinary content. Prototype tests and numerous theoretical innovations have shown that RIS offers advantages in terms of low cost, low power consumption, and simple deployment [1]–[4]. With RIS, the wireless propagation environment (which was previously only adaptable passively) becomes controllable, resulting in the development of a smart radio environment (SRE).

RIS-enhanced cellular networks use RISs to overcome barriers between base stations and users. RISs can serve as a hub for signal reflection and interference mitigation in device-to-device communication networks. They can also cancel unwanted signals through passive beamforming in physical layer security. RISs can improve cell-edge signal strength, reduce neighboring cell interference, and compensate for power loss over long distances. RISs can be deployed on walls to improve the quality of service in indoor scenarios, including virtual reality applications. To avoid blind spots in block-sensitive scenarios such as Wi-Fi networks and visible light communications, a virtual link can be formed between access points and users. RISs can improve the performance of UAV-enabled wireless networks, autonomous vehicular and underwater networks, cellular-connected UAV networks, and intelligent robotic networks by maximizing their benefits. RIS-enhanced IoT networks use RISs to support smart networks such as smart agriculture, smart manufacturing etc. [5]. Fig. 1 presents a simple illustration of a smart radio environment. RIS can handle the impending demands and challenges wireless networks will face. This opens up a wide range of application possibilities and numerous potential opportunities in the 5G and upcoming 6G networks [6], [7].

Motivated by this, the current contribution provides a brief overview of existing research in the field of design specifications on RIS. The rest of this paper is organized as follows. Section II introduces the properties and main evaluation parameters. Section III presents the passive and active RISs. Section IV discusses specifications, materials, and some crucial issues. Section V concludes this work.

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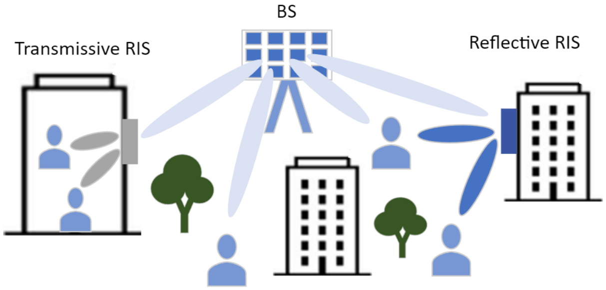

Fig. 1. Illustration of a smart radio environment using RISs

II. GENERAL PROPERTIES AND EVALUATION PARAMETERS

Before starting the design of a reconfigurable intelligent surface, we should take into consideration the design path that we are going to follow and how we could evaluate the overall performance of each structure. In more detail, reconfigurable intelligent surfaces are two-dimensional structures capable of dynamically manipulating electromagnetic waves. RISs use amplitude and phase tunable unit cells to control incident waves via voltage, thermal, optical, or mechanical techniques. Unit cell arrangements can change in response to external stimuli. The literature identifies two hardware design paths for RIS: metasurfaces and antenna arrays [8]. RISs that use metasurface-based cells have a large number of closely spaced sub-wavelengths such as $\lambda/10$, while the unit cells in antenna arrays have a resonant size close to $\lambda/2$, as described in [1], and [9]. Moreover, the metasurface-based unit cells use diffraction to split the incident electromagnetic waves into components based on angle, wavelength, and unit cell period.

Several metrics such as efficiency, power consumption, steering range, and angular resolution are used to evaluate the performance of the structures:

- Efficiency is a key parameter for evaluating RIS hardware. It is calculated as the division of the reflected (or transmitted) power in a certain direction to the total incident power.
- The power consumption includes power for the individual actuators in a unit cell and the controller. Active RISs may require significant power to amplify incident signals before reconfiguration, reflection, and transmission.
- The steering range varies depending on the technique used that is selected in each design. Electronic steering has a limited range while mechanical steering can achieve a wider range.
- The main lobe's beamwidth determines the angular resolution. The beamwidth is affected by the number of unit cells in each surface and the different phase quantization bits that are used. Moreover, both the periodicity and the aperture size of the RIS are defined by the number of unit cells [8].

III. PASSIVE VS ACTIVE RISS

Another important step is to identify the type of surface that is most suitable to address the specifications of our project, as shown in Fig. 2. The majority of existing research focuses on passive RISs. A passive RIS consists of many passive elements that can reflect the incident signal with a controllable phase shift. The elements typically include reflective patches connected to impedance-adjustable circuits. Passive RIS elements consume zero direct-current power and produce minimal thermal noise due to their passive mode of operation, which eliminates the need for active radio-frequency components. However, high capacity gain may not be achieved, particularly in communication scenarios that require a strong direct link between the users and the base stations. Passive RISs introduce a ”multiplicative fading” effect, leading to negative results [10].

Several studies have convergent on the idea that active RISs will address physical limitations in wireless communication systems. Active RISs differ from passive RISs because they can actively reflect signals with amplification. This is achieved with the integration of reflection-type amplifiers into the reflecting elements. Active RIS has the ability to counteract the significant path loss in reflected links, which can potentially overcome the negative impact of ”multiplicative fading”. However, this comes at the cost of higher power consumption. The components generate amplification noise, leading to a reduced signal-to-noise ratio (SNR) at the receiver. Efficient techniques are needed to balance signal and noise amplification. To optimize communication performance, active RISs with a limited power supply should be carefully designed in terms of size (including the number of reflecting elements) and placement [10], [11], and [12]. Active RIS could improve the performance of sixth-generation (6G) wireless applications, including indoor localization and autonomous vehicles, by increasing the signal power, improving transmission reliability, and suppressing interference.

IV. MATERIALS, CONTROL MECHANISMS, AND CRUCIAL ISSUES

As described in [13] and [14] the surfaces can be designed using a variety of methods, including electric, magnetic, thermal, light, external pressure, and electro-optical techniques. An external voltage source can be used to tune the PIN and varactor diodes. RISs can be designed using light-sensitive materials such as graphene, aluminum-doped zinc oxide, indium tin oxide, gallium arsenide, and silicon. Phase-change materials such as liquid crystals and chalcogenide materials

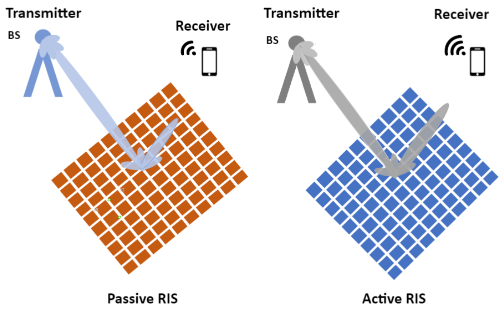

Fig. 2. Illustration of active and passive RISs

are explored. Vanadium dioxide can be used due to its ability to transition from a metal to an insulator in response to temperature changes. Transparent conducting oxides are being considered for near-infrared and mid-infrared RIS designs. Microfluidic, mechanical and MEMS switches can also be used in RIS design. Recent studies indicate that researchers primarily focus on designing sub-6 GHz or 28 GHz frequency bands. RIS can be easily fabricated in these frequency ranges. Most studies include PIN diodes and varactor diodes that are inexpensive, small in size, easily integrated into RIS surfaces, and can operate efficiently at frequencies up to 30 GHz.

However, beyond 5G/6G, RIS will be crucial for wireless communications in the future. The operating frequency for such communications can range from sub-6 GHz to mmWave, including THz and optical frequency bands. Creating a RIS design that is feasible at higher frequencies is an important problem to solve. Designing RIS involves considering its power consumption to achieve minimal power consumption during its operation. RIS configuration should also be simple. The reflected beam should point in the desired direction, which may change if the user moves around and whether there are multiple users at a specific location. Nevertheless, when the source antenna is situated at a considerable distance from the RIS, it can be difficult to direct the radiation in the desired direction. The RIS should accept all incoming waves, irrespective of the polarization or angle of incidence, in an ideal scenario. Nevertheless, the preponderance of the proposed RISs are not polarization-independent and are influenced by the angle of incidence. Furthermore, it is essential to maintain a precise phase difference between unit cells in the design of RIS. The phase difference and communication performance of the RIS can be substantially impacted by minor manufacturing defects. It is anticipated that RIS will possess multifunctional capabilities in the future. Nevertheless, this is a difficult assignment [13]. To address these issues, new materials and new tuning mechanisms for unit cells are currently being developed to reduce power consumption and costs. In addition, machine learning (ML) and artificial intelligence (AI) techniques are used to optimize smart environments [15].

V. CONCLUSIONS

The current state of RIS technology indicates that it will significantly impact communications beyond 5G/6G. Future communications will require a low-cost, self-powered RIS with multifunctional capabilities, such as reflecting beams and detecting incoming signals. RIS is beneficial for high-frequency communication, such as THz, which requires line-of-sight links between the transmitter and receiver. Traditional antenna arrays and metasurfaces are identified as the main design paths in the literature. Active RISs are suggested to improve the limitations of passive surfaces. Current RIS designs primarily use PIN diodes and varactor diodes. Various materials, such as graphene, VO_2, and liquid crystal, show promise for designing RIS. Up until now, most authors have designed RIS for frequencies below 6 GHz. Crucial issues regarding the design of reconfigurable surfaces in higher frequency bands, such as 27–29 GHz and sub-THz have been discussed.

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