A Survey - Intelligent Reflecting Surface Beyond 5G

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Abstract

In the coming decade, we'll see the rollout of the intelligent information society—a highly digitalized, intelligent civilization that draws inspiration from AI and runs on global data. Next-generation or modern communication networks are crucial to bringing this ambitious plan to fruition because of their promise of universal connectivity, full 360-degree wireless coverage, and the seamless integration of all necessary functions to power truly vertical apps. Research in this area has shown that the Intelligent Reflective Surface (IRS) combined with wireless environment management capability is a viable solution for 6G technology. To be more specific, the IRS is capable of precise 3D passive beam formation due to the wavefront's phases, amplitude, frequency, and polarization being controlled intelligently by tunable components. In this article, we provide an overview of the IRS, including categorizing recent IRS research theory, and we also review IRS's structure, controller, tunable chips, and design hardware architecture. Finally, as a timely review of the IRS, our summary will be of interest to both researchers and practitioners involved.

Keywords- Intelligent reflecting surface (IRS) , wireless communications , metasurface , reconfigurable intelligent surface (RIS).

I. Introduction

Reconfigurable intelligent surface (RIS) has been proposed as a novel and cost-effective solution to achieve high spectral and energy efficiency for wireless communications via only low-cost reflecting elements. With a large number of elements whose electromagnetic response (e.g. phase shifts) can be controlled by simple programmable PIN diodes [1]. A metasurface is a two-dimensional electromagnetic (EM) material surface made up of a number of passive scattering units [2]. Furthermore, due to adverse flow conditions, the connection between both the base station (BS) and clients as shown in figure 1 could be extremely prone to blockages, keeping the connection unstable and inefficient. Since this is the case, Intelligent reflecting surface (IRS) technology allows for significant gains in beamforming efficiency with relatively inexpensive hardware [3]. There are several names for the Intelligent Reflecting Surface, including:

Reconfigurable intelligent surface (RIS) : It's a thin, low-cost surface reminiscent of wallpaper that, with the help of software, can alter the direction of radio waves.

Large intelligent metasurface (LIMS) : Several affordable metamaterial antennas passively reflect incident waves by defined phase changes to boost reception signals.

Software-defined metasurface (SDMS) : It creates a tunable wireless environment by manipulating incoming electromagnetic waves' phase, frequency spectrum, and power.

Large intelligent surface (LIS) : System power is reduced with the use of an expansive active antenna array and individual RF chains.

Passive intelligent surface (PIS) : This passively reflects incident waves, making it a viable alternative to active antenna arrays. It's capable of meeting the stringent requirements of 5G networks in terms of data rate and power consumption.

Smart reflect arrays : Like an IRS, these may direct the incident signals toward the user's destination, allowing for a strong connection to be made between transceivers and resolving the issue of signal blockages in mmWave indoor communications.

LIS, RIS, LIMS, SDMS, and IRS are interchangeable; all these eco-friendly technologies should enhance the energy efficiency (EE) and spectral efficienc (SE) in the same, cost-effective ways. They often rely on phase shifting without amplification to reshape the incident signal for the intended user, optimizing efficiency without performing any signal processing [4].

II. RELATED WORK

We now categorize recent IRS research. We go over capacity/data rate assessments, energy optimization, channel capacity, settings, and reliability analysis for IRS-aided communications, including secure communications, terminal positioning, and other cutting-edge technologies [5].

In order to comprehend the idea of IM approaches using intelligent surfaces, the authors presented the big intelligent surface-spatial modulator (LIS-SM) and LIS-space shifts keying (SSK) schemes. These methods integrate the phase optimizing of the intelligent surface with the notion of index modulation to boost spectral efficiency and signal quality. The maximum energy sub-optimal and exhausting search-based optimum detectors are brought together in a single theoretical framework to determine the average bit error probability. Based on computational modeling, the resulting bit error probability is significantly lower than that of conventional completely digital precoding-based receiving SSK techniques [6].

The authors suggested combining the optimization of the transmission covariance matrix and IRS reflection coefficient as a means of characterizing the basic capacity limit of RIS-aided MIMO communication networks [7].

Guo et al. [8] found the best active beamforming just at the BS and passive beamforming at IRS to optimize the weight value of downlink rates, where the weights indicate the preference of a mobile user. They assumed that the IRS phase shifts could only take discrete values to make optimization analysis easier and more feasible.

B. Zheng et al. [2] considered an inter-IRS channel multiplication beamforming gain by using a collaborative passive beamforming structure for two-IRS assisted multiuser MIMO. The authors optimized the constructive actually received beamforming at the BS and the collaborative passive reflect beamforming at primary and secondary IRSs located close to the BS and subscribers, respectively, to improve the limited-level signal-to-interference-plus-noise (SINR) IRS over the single in connection to the achievable max-min data rate.

The authors in [8] utilized a PIN diode as a component of a metasurface in a frequency range of around 2.466 GHz and developed and demonstrated a binary state programmable device based on hybrid resonators. Integrated circuits (ICs) with continually adjustable load impedance are designed to regulate the phase variations of scattering elements, and the tunable chips can be in the form of varactor diodes, which permit continuous tuning in response to varying voltage bias. The gate voltage allows for independent control of the ICs' capacitance and resistance. Therefore, one can manipulate waves by precisely adjusting the biasing voltages.

In a multi-user MISO transmission system, the IRS adds a defined amount of both phase and amplitude for each node. We design a transmission power method by estimating the BS's optimum transmit precoding and IRS's finite element shifts based on user receiver SINR restrictions. The authors first explore the situation where the IRS aids just one user and then provide both positive and negative algorithms for that scenario. Additionally, the IRS employing discontinuous phase shifts obtains the same square voltage gain with an approximately large number of reflective components at the cost of a steady proportionate power loss that increases with the quantization levels after phase shift. Recommendations are given for both single-user and multiple-user scenarios with IRS-eligible users. This simulation compares IRS component representations to various standard schemes [9].

Ning et al. [10] maximize privacy by employing an active beamformer at the base station and a passive phase shifter on the IRS. Together, both the phase shifter and beamformer are optimized to solve the non-convex problem.

III. INTELLIGENT REFLECTING SURFACE THEORY AND DESIGN

The industry has begun research on sixth-generation (6G) communication with the rollout of fifth-generation (5G) mobile communication. In addition to meeting the higher performance needs in communication, we must also handle rising prices and energy usage in 6G. Intelligent reflective surfaces (IRSs) are a key component of 6G technology that can address the dual challenges of low efficiency and high cost in wireless networking. Consequently, there has been a rise in interest in this area in recent years [11]. Metasurfaces are a type of man-made, two-dimensional material that, depending on their structural features, exhibit unique electromagnetic properties. The metasurface depicted in Figure 1 is made up of a vast collection of passive scattering materials ,

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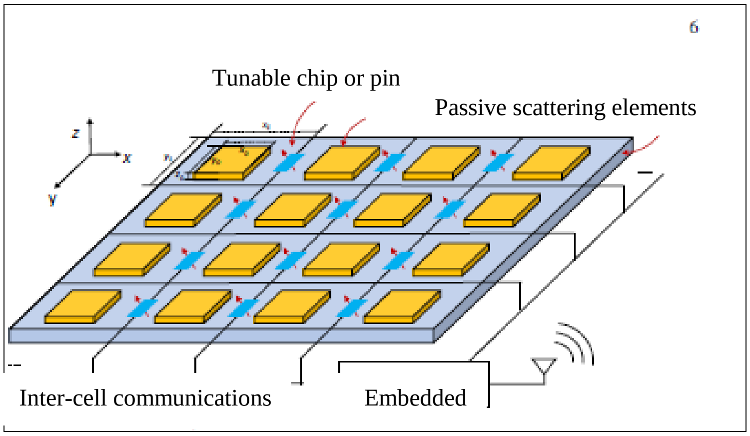

Fig 1. Material and Structural Shape

such as metallic or dielectric particles, can alter incident electromagnetic (EM) waves in many ways. The transformation of incident waves, including the reflection and diffraction of waves in different directions and intensities, is determined by the sub-wavelength structure of the scattering elements. When EM waves travel to a border between two mediums, the reflected and diffracted waves normally follow the Fresnel formulas and Snell's law in terms of their incident and scattered waves.as shown in Figure 2.

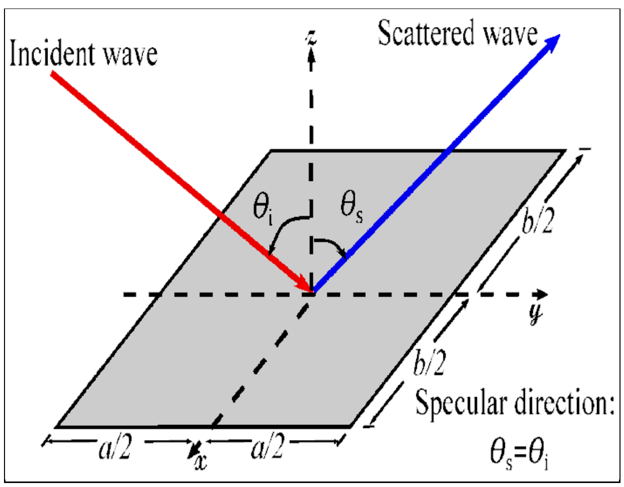

Fig.2: Waves That are Incident and Scattered

When the same waves reach a metasurface , things change. The resonance frequency, and by extension, the boundary conditions can be altered due to the periodic structure of the scattering elements. Thus, the waves that are reflected and diffracted will have extra phase shifts, as shown in Figure 3.

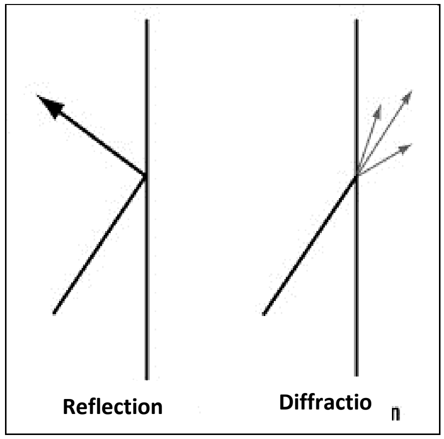

Fig.3: Reflection and Diffraction phase

Which is why an IRS is often set up in close proximity to the end-users to enhance local communications. Moreover, an alternative IRS deployment strategy involves placing the IRS in close proximity to the Base Station (BS) or Access Point (AP), enabling the BS/AP to achieve signal quality on par with such a massive MIMO BS/AP by leveraging the nearby IRSs to enable perfectly adequate passive beamforming towards its delivered users [12].

A. *THE IRS'S STRUCTURE AND MECHANISM*

It is often assumed that the Layer 0 wireless system between a transmitting device and its receiving device is unregulated and determined by "nature." By moving the supporting action down to Layer 0, RIS technology improves upon this and has the potential to significantly alter wireless systems beyond the 5G standard [13].In order to perform their primary function, RISs depend on the physical premise that the spread of electric impulses over a surface defines the electromagnetic (EM) emissions from that surface. The impinging EM waves generate surface currents, and RISs intend to consciously adjust the distribution over them to enable novel EM functions like wave absorption, thumping reflections, and reflection phase manipulation Varactors , PIN diodes, and microelectromechanical system (MEMS) switches are examples of ultra-fast switching elements used to regulate the RIS components at hand.

To rephrase, wireless network designers can counteract the detrimental impacts of natural radio propagation by strategically placing software-defined RISs in propagation environments and manipulating the radio waves' scatter, reflection, and refraction properties. A RIS setup usually has three distinct levels. The outermost layer is made up of a huge number of small metallic patch elements imprinted on dielectric material to immediately interact with incoming signals. The second layer is a conducting backplane that blocks radiation from the RIS's front side. The third and final layer of a RIS, as opposed to a passive reflect-array, has control circuits coupled to a micro-controller in order to configure the RIS based on instructions from a central console or base station. Although its functioning is passive, the RIS requires electricity for microcontrollers and switch parts, ensuring that signal reflection does not require any external power [14]. The time, frequency, and spatial-domain characteristics of the BS signal can be adjusted with relative ease, allowing for fine-tuning of its received power and beamforming to achieve optimal measurement precision. When operating as transmitters or reflectors, a RIS's signals can be modified by a RIS control to further improve accuracy [15].

B. *IRS CONTROLLER AND TUNABLE CHIPS*

The fabrication of RIS is made possible by the fact that thin resonant cavities can accurately reflect receiving waves with a tunable reflection phase. The most basic approach involves adding varactor diodes to each RIS cell to enable reconfiguration .The real, material shape of the structure is shown in Figure 4 , it is a periodic surface constructed of square metal patches supplied with varactor diodes. Each surface unit cell's reflection properties can be modified as a result of the DC voltage between neighboring cells. Beamforming involves adjusting the phase shift of varactors in such a way that each user receives the maximum amount of transmitted power. This can be achieved in the microwave range by incorporating varactors or PIN diodes into the substrate [16]. A reflow soldering process is used to solder the PIN diodes. All PIN diodes can be turned on and off at once because their positive poles are connected in series with the negative poles (ground wires) of the metasurface bias line. These PIN diodes are always in their off and on states, respectively, the EM characteristics of which (such as capacitances) are highly changeable by varying the voltage applied to the device. By manipulating the voltage of individual component cells, the reflected fields can be sculpted and controlled to produce the required phase/amplitude profiles. Varactor-controlled electrical steerable reflectors have been shown in the microwave regime since the 2000s [17]. Tuning the EM properties of metadevices is also possible by loading free carriers in conductive materials using electric gating techniques and photoexcitation. Traditional semiconductors (like GaAs, silicon, and germanium) and atomically thin 2D elements [18]. are effective in this regard. Another potent method of modifying the EM properties of metadevices is mechanical tuning, which entails changing the shape and environment of elastic structures or microfluidic systems [19]. Due to the spread of the received signal, bidirectional reflector technique was utilized to boost the system's performance. As a result, this technology has proven that it can fix reflected signals [20].

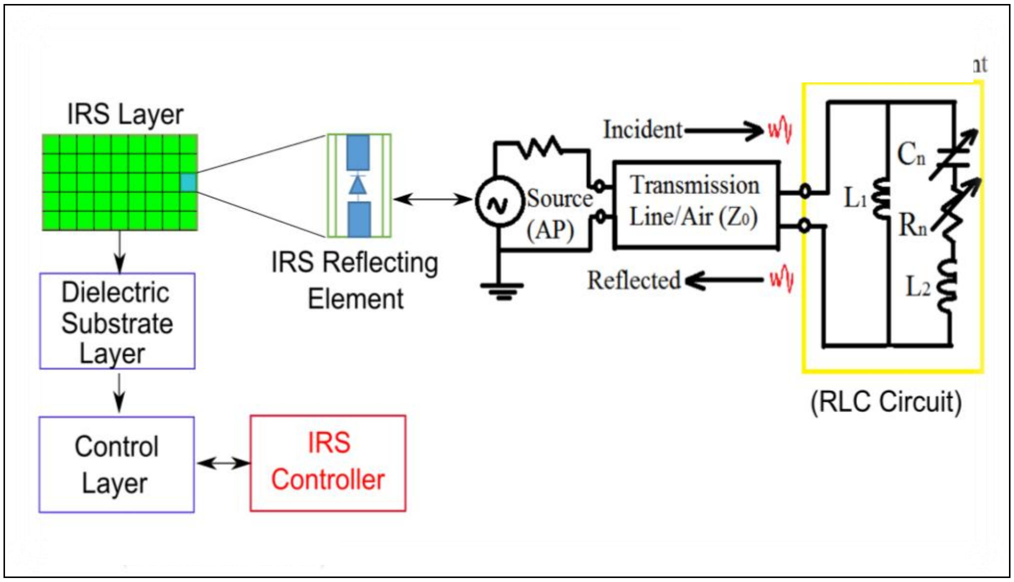

Fig.4: IRS Architecture

C. *HARDWARE ARCHITECTURE DESIGN*

Most IRS are what are known as passive metasurfaces, which implies that their functionality is locked in once the devices are manufactured. Currently, there is a push to learn more about active and tunable metasurfaces, which can be reconfigured to manipulate electromagnetic (EM) waves and provide a versatile platform for future multifunctional devices [20]. We will review the Passive RIS and Active RIS types.

Passive RISs: Passive RIS performs similarly to a metal mirror or pulse collector, but with the added ability to be controlled by software and alter the incoming electromagnetic field. A passive RIS differs from its active equivalent in that it does not feature any active components and does not need any external power sources. Using energy collecting modules to power their circuits and embedded sensors might make them completely self-sufficient in terms of energy consumption. Passive RIS technology is appealing from a power consumption perspective because of its capacity to reshape radio signals impinging upon it, forwarding the received signal using neither a power supply nor RF link, and even without designers' signal processing. In addition, passive RISs need only a low-rate control link to operate in full duplex operation without experiencing considerable self-interference or a rise in the noise level. Last but not least, passive RIS structures are simple to incorporate into the modern communications environment due to their low power requirements and hardware costs [21] .A passive RIS was utilized to improve the overall transmit signal quality of both single-antenna and multiple-antenna systems [22].

Figure 1 depicts the RIS's role in passive beamforming between the BS and the user via reflecting the signals to facilitate conversation. The BS can adjust its RIS reflection coefficients with the use of an RIS controller. In addition, to improve communication performance, both passive beamforming just at RIS and send beamforming only at BS must be created [23]. RISs have largely been utilized in passive beamforming to improve end-to-end communications. Nonetheless, RISs need data transport. RIS intracellular signaling changes RISs must regularly update transceivers for optimal cooperation. The RIS must transmit its status to the data packet transmission media to maintain synchronization [24].

Active RISs: An RIS structure with active reflecting components has recently been presented as a solution to this difficulty. This architecture allows for the magnitude or phase of the incident wave to be configured, albeit it does so at the expense of an increased amount of power consumption. Hence, in contrast to the passive RISs, these active RISs reflect incident signals with amplification by applying additional power circuitry. This is in contrast to the passive RISs [22].

IV. FEATURES AND ADVANTAGES OF RIS

Easy to deploy: Passive electromagnetic (EM) systems make RISs easy to install, make amplifiers cheaper and more dependable, and improve energy efficiency, lowering RF emissions and disturbances while reducing costs associated with diesel consumption.
Spectral efficiency enhancement: RISs can offset long-distance wireless power loss, and radio transmissions can passively connect phones and access points. Bandwidth increases considerably when high structures block line-of-sight connections between access points and clients.
Environmentally friendly: RISs can control the signal without a power amplifier by controlling the phase shift from each reflecting component. RISs are greener than AF and DF arrangements [25]. The IRS gives the host system software better control over RF signals because it's so easy to integrate [26]. The distributed dispersion of many RISs allows for more energy-efficient optimization than single-RIS systems [27].
In wireless networks, an IRS offers a new approach and benefits when mMIMO, AF, and decode-forward (DF) relays, and backscatter communication are all used. According to Table (1), an IRS is compared to other similar technologies concisely.

Technology	Duplex Mode	Role	Noise	Power Budget	Interference	Energy Utility	Hardware Cost
*IRS	Full	Helper	No	Passive Low	Very Low	Low	Low
*AF Relay	Half	Helper	Additive	Active High	High	High	High
*DF Relay	Full	Helper	Additive	Active High	High	High	High
*Back-Scatter	Full	Source	Additive	Active Low	Low	Very Low	Low
*m3MIMO	Full	Source	Additive	Active Very High	High	Very High	High

Table.1: IRS is Compared to Other Technologies

•**IRS vs. mMIMO**: IRS and effective smart surface-based massive MIMO are different systems because of their array architectures (passive vs. active) or operation (reflection vs. transmission).
•**IRS vs. AF Relay**: AF relays enhance and generate source-destination signals, while IRSs passively reflect them as an array. IRS uses full-duplex mode, making it more spectrally efficient than AF, which uses half-duplex mode to avoid interference.
•**IRS vs. DF Relay**: DF relaying decodes and retransmits the signal, like AF relaying. Decoding is far more complicated and resource-intensive. As it does not decode, the IRS only passively reflects. This reduces production costs and energy use.
• **IRS vs. Back-Scatter**: In RFID, a reader-to-receiver four-digit identification tag, the IRS improves communication rather than sending data via reflection. In backscatter communication, the receiver must eliminate or regulate reader or receiver interference. When using IRS to aid communications, both direct- and reflect-path signals are informative and can be used at the receiver to improve the signal [4].

V. THE SIMILARITY BETWEEN SMART ANTENNAS AND RECONFIGURABLE INTELLIGENT SURFACES

Given the size of the chasm between the potential of wireless communications in the future and their current performance, a great deal of investigation must be conducted before the vision for the future of communications can become a reality [29].The two technologies are working on A possible strategy to extend the life of wireless nodes and, by extension, reduce the energy bottleneck in energy-constrained wireless networks is the transfer of both data and power across wireless connections at the same time. As an stand by to existing methods of energy collection[30]. The similarity between smart antennas and reconfigurable intelligent surfaces (RIS) is that both technologies can dynamically adjust their properties to improve wireless communication performance.
Smart antennas and RIS both use signal processing algorithms to adapt to changes in the wireless environment. Smart antennas can adjust the direction of their radiation pattern to optimize signal reception, while RIS can manipulate the reflection and propagation of wireless signals to create desired signal paths. Another similarity between smart antennas and RIS is that they both rely on multiple antenna elements to achieve their objectives [31]. Smart antennas use multiple antenna elements to create a beamforming pattern that

can adapt to the signal environment, while RIS use an array of reflecting elements to manipulate the propagation of signals. Finally, both smart antennas and RIS have the potential to improve the performance of wireless communication systems in a variety of applications, including cellular networks, satellite communications, and indoor wireless systems. Overall, the similarities between smart antennas and RIS lie in their ability to dynamically adjust their properties and enhance wireless communication performance through signal processing and multiple antenna elements [32].

VI. CONCLUSION

This research provides an overview of the IRS design as a promising technique for Beyond 5G wireless networks and explains the significance of IRS in wireless communication. The ability of an IRS to assist in the simultaneous optimization of the transmitter and receiver is also discussed. In particular, this survey outlines the advantages of IRS over alternative technologies and provides a comprehensive discussion on the IRS system architecture, including its structure, performance limits, distinguishing features, and advantages. Additionally, IRS is briefly compared to related technologies. Finally, the similarity between smart antennas and reconfigurable intelligent surfaces (RIS) is explained.

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