ADVANCED RESEARCH & INNOVATIONS
International Journal of Advanced Research & Innovations
Volume 15, Issue-2
September, 2025, P68
ISSN: 2319-9253

International Conference on Emerging Trends in Engineering, Technology & Management (ICETM-2025)
Conducted by *Viswam Engineering College (UGC—Autonomous Institution)* held on 11th & 12th, April- 2025

A SURVEY ON INTELLIGENT REFLECTING SURFACES

T. Reddi Rani[1]
[1]Associate professor, Dept. of ECE, Viswam Engineering College, Madanapalle

ABSTRACT: Using intelligent reflecting surfaces (IRSs) to improve the coverage and the data rate of future wireless networks is a viable option. These surfaces are constituted of a significant number of passive and nearly passive components that interact with incident signals in a smart way, such as by reflecting them, to increase the wireless system's performance as a result of which the notion of a smart radio environment comes to fruition. In this survey we supply a study review of IRS-assisted wireless communication starting with the principles of IRS which include the hardware architecture, the control mechanisms, and the discussions of previously held views about the channel model and path loss, then the performance analysis considering different performance parameters, analytical approaches and metrics are presented to describe the IRS-assisted wireless network performance improvements. Despite its enormous promise, IRS confronts new hurdles in integrating into wireless networks efficiently due to its passive nature. Consequently, the channel estimation for, both full and nearly passive IRS and the IRS deployments are compared under various wireless communication models and for single and multi-users. Lastly, we propose the challenges and potential future study areas for the IRS aided wireless communication systems.

Keywords: *intelligent reflecting surfaces (IRS), reconfigurable intelligent surfaces*

1. INTRODUCTION

Although the evolutionary aspect of 5G has acquired substantial traction, the promised revolutionary view of5G — a system running nearly entirely at millimeter wave (mm Wave) frequencies and enabling diverse Internet of things (IoE) services. Although the 5G wireless network is still deployed around the world, both academia and industry are excited about the future beyond 5G which seeks to satisfy more demanding requirements than 5G. Fig.1 shows the vision and the expectation for the Next generation of 5G i.e., 6G key performance requirements in comparison with 5G. for example, the performance requirements for 6G are a peak data rate of 1,000 Gbps and air latency less than 100 microseconds (µs), 50 times the peak data rate and one-tenth the latency of5G.

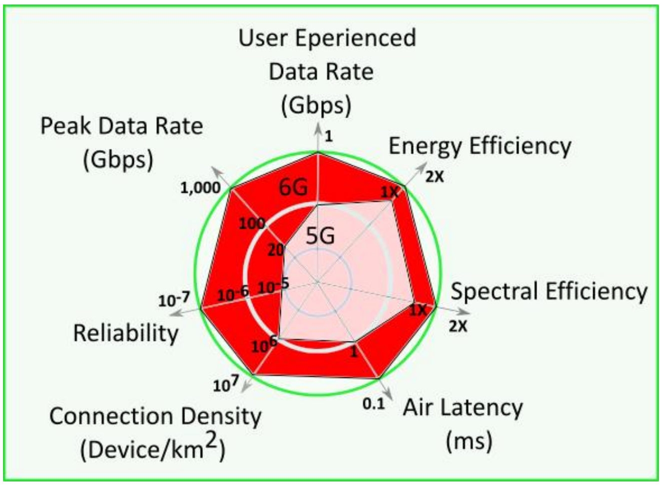

Fig.1. Comparison between 5G and 6G

Volume 15, Issue-2
September, 2025, P68
ISSN: 2319-9253

As a result, it is critical to developing sustainably new and inventive technologies in order to enable future wireless network capacity increase at a moderate and manageable bud- get, complexities, and power consumption with the widespread adoption of user devices that will form the future of IoT.

The existing modern physical layer solutions are in sufficient, and overall progress is still modest, necessitating new and radical physical layer solutions. There is attracting attention in new communication patterns that exploit the propagation environment's extreme randomness to achieve the target of the simplicity of the transceiver components and the quality of service (QoS). The intelligent reflecting surface (IRS) has recently been created in the wireless communications academic researchers. The IRS is a fundamental facilitator for achieving the concept of smart radio environments (SREs) by rendering the wireless environment configurable and adjustable.

Fig.2 shows a typical IRS-assisted wireless communication system model. An IRS controller is used to program the IRS reflecting elements. Furthermore, the controller communicates with the base station (BS) by another wireless signal in order for the BS to control the IRS reflections by creating a phase shift matrix theta that results from modifying huge cheap passive reflecting components to configure the channel, and thus the concept of passive signal reflections is introduced in the research.

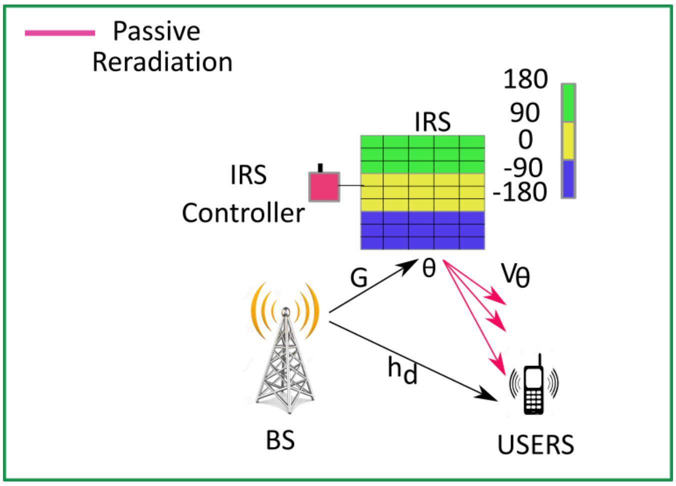

Fig. 2. IRS assisted wireless communication

Wireless networks aided by the IRS are expected to change the existing network optimization patterns by incorporating the smart wireless environment into network optimization issues and are predicted to take a proactive role in the future wireless networks. There have been several recent works reviewing the RIS based smart radio environment, and repeating these reviews would not do a fair study however in comparison to prior publications, our work provides a thorough investigation of the IRS's theoretical foundations as well as a current evaluation of its most recent uses in wireless networks. The following are the highlights of our important contributions:

An extensive study for the recent IRS works including areas of research that are not covered in the prior review publications. For instance, the majority of the authors are relying on the alternating optimization (AO) method with sophisticated techniques and algorithms to maximize the data rate. In addition to that large number of papers concentrate on joint power and reflection coefficients optimizations or jointly active and passive optimization which require more power consumption and training overhead however, more advanced pilot transmission dedicated to aiding the IRS systems necessitates more exploration and investigation. Furthermore, depending on the orthogonal frequency division multiplexing (OFDM) technology in mitigating the frequency selective fading channels into flat fading channels is not enough in wireless aided IRS systems. Information coding for each user can be combined with OFDM to form multi-carrier code division.

Table 1. LIST OF PUBLICATIONS RELATED TO IRS

Reference	Surface Architecture	Control Mechanism	System Setup	Achievement
[12]	Active frequency selective surfaces (FSS) with PIN diodes connecting metal parts of the FSS	ON-OFF PIN Diodes	Multi-user wideband indoor downlink OFDMA s	Surfaces that are fully reflected with proper coverage and can boost system performance by up to 80%
[13]	Programmable Radio Environment for Smart Spaces (PRESS) Low-Cost antenna elements connected to passive loads and embedded in the walls of a building	prototype PRESS elements equipped with (SP4T) RF switches change phase of each antenna by π/2	Multi-client's wideband system	Passively reflect or actively transmit radio waves, and so attenuate or enhance signal strength by up to 26 dB, to reconfigure multipath propagation
[14]	Hyper Surface tile equipped with physical switch elements	Switch element Controllable state (ON/OFF)	12 receivers, in both microwave and mmWave frequency bands, are uniformly distributed in indoor space and are evaluated using a map-based ray-tracer	Re-engineering electromagnetic waves, including steering in any direction, complete absorption, polarisation modification, and other techniques. With maximum and minimum received power of 32.5 dBm and 12.4 dBm, respectively, and an average received power of 20.6 dBm, the results demonstrate Good

				Coverage.
[17]	spatial microwave modulators (SMM) equipped with102 controllable electromagnetic reflectors	Two states of resonant elements (the reflector and the parasitic strip), π state and 0 state	Two antennas source and receiver connected to network analyzer are located in a room that the spatial microwave modulator can be placed on the walls of the room	Increasing or cancelling the wireless transmission amplitude between two antennas (Shaping complex microwave field). SMM can perform wave front shaping and concealing the field around one single antenna on a correlation length wide area (6 cm at 2.4 GHz)
[18]	reflect-array panel with totally 48 reflector units and its peripheral circuits and varactors	each reflector is controlled by a bias voltage to tune the varactors (0.6 − 8pF) for changing the capacitance and hence the phase of each unit	Two pairs of wireless users in a conference room where smart reflect array hung on the walls	Controlling the phase shift of each reflect array element. The interference has been eliminated, and the interference-plus-noise ratio (SINR) has been enhanced to around 30 dB, according to the achieved results
[19]	intelligent receiving antenna array	the information transfer capabilities of an intelligent surface for every m2 deployed surface area	Multi-user narrow band system with ideal free space propagation	Active surface for transmission and reception. Consequently, the limit of the normalized capacity is enhanced when the wavelength approaches zero
[20]	Hyper surface tile with controllers that regulate the metal surface's switch components	Dynamic meta-atoms include phase switching components like MEMS, CMOS transistors, or micro fluidic	m-wave setups that include a Rx & Tx pair situated in NLOS over a defined floor plan and walls	New physical layer security features can help avoid eavesdropping. Path loss and multipath fading mitigation, as well as eavesdropping

		switches that can change the structure of the metal atom	covered with hyper surface	security, were proven in the 2.4 and 60 GHz configurations
[21]	plasmonic antenna elements at each transceiver side	New intelligent plasmonic antenna arrays that can function in transmission, reception, reflection, and waveguiding, the mm-wave and THz-bands	Ultra-Massive MIMO (UM MIMO)	In the mm-wave and THz-bands, new intelligent plasmonic antenna arrays capable of communications and waveguiding have been developed. The results demonstrate a significant increase in transmission distance and data rate
[22]	IRS-assisted free-space optical (FSO) systems	comparable mirror-assisted technology, which can be used to create a phase-shift profile that spans the IRS	A FSO communication system consists of a Tx with a Gaussian beam-emitting laser source (LS), an IRS, and a Rx with a lens and a photo detector (PD)	FSO systems with IRS assistance can compensate the need for a LOS between Tx and Rx. The effect on the end-to-end channel varies depending on where TX, IRS, and RX are in relation to each other
[23]	102 phase-binary components make up the metasurface	The phase shift of the reflected wave may be electrically controlled for each element using a PIN Diode bias voltage from an Arduino microcontroller to be either 0 or π	The transfer of an RGB colour image across a 3-3 MIMO system was simulated using wireless image transmission in an office room	The benefit of shaping wireless channels. Physical shaping of propagation media with simple metasurfaces may achieve complete orthogonality of wireless channels and excellent channel diversity and low crosstalk
[24]	Reconfigurable Intelligent	a method of encoding	SIMO over a quasi-static	To boost capacity, a method is utilized that

	Surface (RIS) with 16 elements	information in both the sent signal and the RIS configuration	fading channel	encodes data in the sent signal as well as the RIS configuration. Three times quicker than max-SNR encoding is the joint encoding.
[25]	RIS with large reflecting elements	The best RIS phase shift configuration	Multiple antennas at the transmitter and receiver in a point-to-point RIS-based system	Developing an overhead-aware resource allocation framework where RIS used to improve the performance (SE/EE) of the system
[26]	256 unit cell programmable surfaces based on varactor diodes	A digital to analogue converter generates an external control signal that controls the phase response of the unit cell	RIS-assisted MIMO wireless system	The proposed prototype implements realtime RIS based MIMO-QAM wireless communication with less power consumption and achievable data rate 20 Mbps

2. IRS HARDWARE AND FUNCTIONALITY

In this part, we cover the fundamentals of IRS-assisted wire- less communication, including the major IRS Architecture, hardware, and control mechanism, as well as the signal and channel models presented in the existing works of literature.

A. IRS Architecture and Control Mechanism

Snell's law and the Fresnel equations control the intensities and directions of reflected and diffracted waves. When the wave collides with a meta surface, the situation changes. A shifting in the resonance frequency and, as a result, changes in the boundary conditions might emerge from the periodic arrangement of the scattering components. Hence, extra phase shifts will be carried by the reflected and diffracted waves. The EM characteristics of the meta surface will be fixed once it is produced with a certain physical structure, allowing it to be utilized for a given aim, such as a ideal absorber working at a specific frequency. The IRS is made up of a programmable meta surface that can completely regulate the phase changes that individual scattering components experience. This can be accomplished by applying outside stimulus to the scattering components, causing their physical characteristics to alter, resulting in a change in the meta surface's EM properties without refabrication.

Fig.4 depicts a typical IRS design, which includes three layers and a smart controller. The first layer (IRS Layer) is made up of a dielectric substrate with several tunable and reconfigurable metallic patches put on it to directly regulate incoming waves. A copper substance is typically used in the second layer to avoid

Volume 15, Issue-2
September, 2025, P68
ISSN: 2319-9253

transmission power losses due to IRS reflection. The third layer is a control integrated board that is in charge of both excitation and real-time control of the reflecting elements' reflection amplitudes and phase shifts.

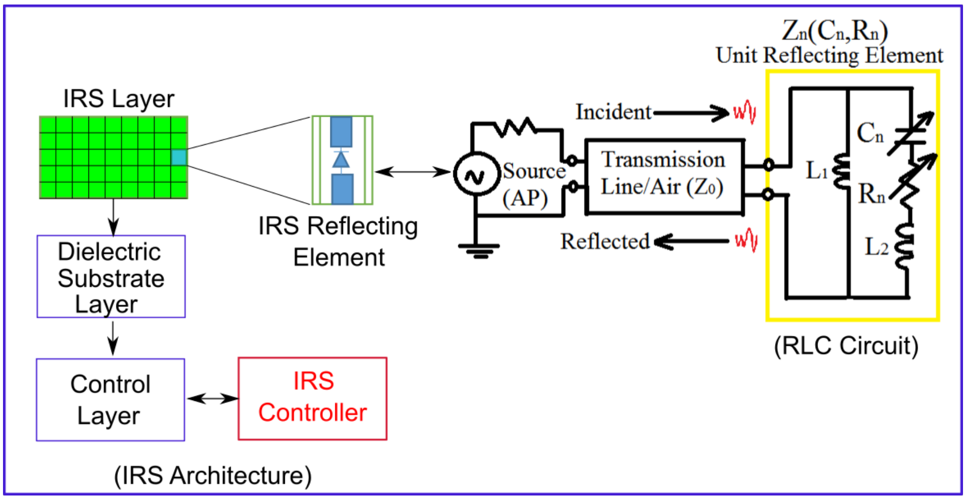

Fig. 4. the structure of the IRS including its reflecting element and the equivalent RLC circuit model

In practice, dedicated sensors can be deployed in the first layer, for example, interlaced with the IRS's reflecting elements, to detect the surrounding radio signals of interest and assist the smart controller in designing the reflection coefficients, to enhance IRS's environmental learning capability. There are three basic categories for the different tuning processes that have been proven in the literature namely:

1). Circuit tuning comprises the aimed integration or modification of individual impedance into the unit cell circuit model using changeable capacitors and switches inside and between unit cells

2) Geometric tuning refers to techniques that change the form of the unit cell physically, causing the accompanying circuit model to change dramatically

3) Material tuning is the process of modifying the material properties of a substrate or small section of a unit cell to change the responsiveness and characteristics of the substrate layer, or small component of the unit cell. In phase shift materials and liquid crystal devices, this technology is applied

B. Signal and Channel Model

IRS can be coated on the front of buildings in the wireless environment, such as solid structures and top surfaces of rooms, or carried on aerial vehicles, such as not fixed balloons in the air and UAVs, to achieve the idea of the smart radio environment. As a result, for modelling and performance analysis of IRS-aided wireless communication, scientific analysis models that consider the geographical placements of IRS elements, the IRS's electromagnetic characteristics, and the wave modifications utilized by adjacent IRS elements in the environment are necessary. A sent radio signal in a typical wireless communication environment contacts many objects along the route, resulting in duplicates of the transmitted wave which comes across reflection, diffraction, and dispersion. Multipath components are signal copies that reach the receiver with randomly and unexpectedly different amplitudes, phase shifts, and signal delays, causing considerable distortions in the received signal due to their relative constructive or destructive addition. This is termed as fading in wireless communication systems, and it is a critical parameter in existing and future wireless communication systems.

The basic goal of IRS is to establish a controllable wire- less communication in which the extremely unpredictable radio channel is turned into a controllable space by carefully modifying electromagnetic signal propagation in a software- controlled manner.

Table 2 is a summary of some of the work done in the performance system analysis considering the usage of the intelligent reflecting surfaces as a reflector, receiver, and transmitter in addition to the design objectives. We believe that in order to construct genuinely widespread wireless networks that can provide continuous communication and good quality of service (QoS) to numerous users in such a challenging wire- less environment, new and radical solutions are still required.

Table 2. SUMMARY OF EXISTING WORK IN THE FIELD OF IRS SYSTEMS

Reference	Communication setup	IRS functionality	Criterion for measuring performance	Design Goal
[50]	MIMO	Transmitter	Bit Error Rate (BIR)	Enhance the performance and boost the spectral efficiency
[51]	SISO in the presence of random objects	Reflector	Probability of being a reflector	If an item is coated in meta surfaces, the chance that it is a reflector is unaffected by its length, but it is strongly affected if Snell's law of reflection must be applied
[52]	SISO mm-wave communications with Blocked LOS	Reflector	Outage probability	Even when the links are impeded by barriers, a reflect-array deployment may provide reliable mm-Wave connections for indoor communications
[53]	MISO	Reflector	Outage probability	The effects of several critical system factors on the ideal outage probability are analysed to

Volume 15, Issue-2
September, 2025, P68
ISSN: 2319-9253

				uncover crucial design insights
[54]	SISO in the presence of both line-of-sight signal blockages and reflectors	Reflector	Coverage probability	Improving the coverage in high-density networks
[57]	SISO under double Nakagami-m channels	Reflector	Bit error probability	Performance improvement
[58]	SISO under Rayleigh fading channel	Reflector and Transmitter	Symbol error probability (SEP)	Increasing the received SNR
[60]	Multi-users NOMA system	Reflector	Bit Error Rate (BIR)	Improving system performance and reliability
[61]	Multi-users MISO	Reflector	Symbol error rate (SER)	Optimal SNR and increase Sum rate
[64]	mm-wave MIMO	Reflector	Achievable Rate	High rate in low SNR
[65]	Point to point MIMO	Reflector	Achievable Rate	Rate by choosing proper IRS deployment and phases
[66]	Narrow band SISO	Reflector	Achievable data rate	Maximize data rate
[68]	Single BS-Multiusers	Reflector	Spatial throughput	Maximize spatial throughput for users
[69]	Single BS-Multiusers	Reflector	Achievable data rate	Sum Rate enhancement
[70]	Single AP-Multiuser	Reflector	Achievable user Rate	Superior rate performance of centralized over distributed
[71]	SISO	Reflector	Coverage Probability	Increasing the number of surfaces

				surpasses the design technique of increasing the number of elements per surface.
[72]	Uplink LIS-based large antenna-array system for single Antenna multiusers	Receiver	Ergodic Rate	Produce performance comparable to traditional massive MIM
[73]	Uplink single user to signal processing unit	Receiver	Capacity	Reducing the impact of hardware impairments
[74]	MU-MISO	Reflector	Sum SE	Enhance sum SE
[75]	Single antenna radiating to LIS	Receiver	Coverage positioning	Distributed deployments have the ability to expand terminal placement coverage and deliver superior average CramerRao lower bound (CRLBs) in all dimensions
[84]	MISO	Reflector	Coverage probability and average throughput	Improve system coverage probability and throughput without consuming more energy.
[85]	MISO-OFDM	Reflector	Downlink rate	Downlink rate enhancement despite the lack of independent RIS phase control

[86]	Single user SISO	Reflector Array	Outage probability and the average bit-error probability	The RIS-assisted system outperforms the AF relay system with fewer reflecting elements
[87]	Single source and two wireless sensor nodes	Reflector	Average symbol error probability (ASER) and the outage probability	As the number of reflecting elements (RE) grows, the performance improves
[88]	IRS-assisted NOMA	Forward Relay	Outage probability and ergodic rate	Enhance energy efficiency compared to conventional cooperative communications.

3. CONCLUSION:

This paper provided a thorough overview of the IRS's architecture and uses in wireless communication networks. In the beginning, we have presented the IRS principles. The paper also gives various relevant IRS publications and existing work in the field of IRS systems Finally; we have identified significant open challenges and future directions.

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Volume 15, Issue-2
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