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A Survey on Beamforming and Adaptive Intelligent Surfaces to Improve The Performance of Wireless Communication Systems

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Abstract: In wireless communication Adaptive Intelligent Surfaces (AIS) have emerged as a revolutionary technology in enabling the manipulation of electromagnetic waves through reconfigurable metasurfaces. These surfaces have the capability to reshape incident waves by dynamically modifying their electromagnetic properties. Beamforming, a fundamental signal processing technique, plays a pivotal role in optimizing the performance of AIS-enabled communication systems. This review paper comprehensively surveys the state-of-the-art beamforming techniques employed with adaptive intelligent surfaces. It discusses various AIS techniques, optimization strategies, and practical implementations, highlighting their benefits, limitations, and potential applications. Furthermore, the paper delves into the challenges associated with real-world deployment and provides insights into future research directions..

Keywords: *Adaptive Intelligent Surface, Beamforming, Reconfigurable*

Introduction-

The objective behind carrying out the review is to categorize the various approaches which are available for the next generation wireless communication using AIS. By surveying the available literature on the AIS we can find out the challenges and limitations in implementation and use of this technology for next generation wireless communication.

The ever-increasing demand of higher data rates, enhanced spectral efficiency, and seamless connectivity has driven the development of novel technologies in the field of wireless communications. Adaptive Intelligent Surfaces (AIS), also known as reconfigurable intelligent surfaces or smart reflectors, have emerged as a transformative solution to address these challenges. In traditional wireless communication systems, beamforming techniques have been widely used to enhance the signal-to-noise ratio (SNR) and achieve better communication performance. Beamforming involves adjusting the phases and amplitudes of multiple antenna elements to focus the transmitted or received signal in a specific direction. This directional focus improves the signal quality at the intended receiver while reducing interference from other directions.

AIS have the unique ability to manipulate electromagnetic waves by modifying their properties, such as phase, amplitude, and polarization. By configuring the AIS appropriately, beamforming can be used to strengthen the signal at specific desired locations, compensating for signal losses due to path attenuation, obstacles, or interference. In wireless communication, multipath propagation can lead to fading and interference. By intelligently adjusting the reflection properties of AIS, beamforming can be employed to control the direction of the reflected waves, effectively managing multipath effects and reducing signal degradation. AIS can act as virtual mirrors that redirect signals towards areas with poor coverage, such as indoor spaces or remote locations. By applying beamforming, the signal can be concentrated in these challenging regions, extending the coverage and improving overall connectivity. Traditional beamforming techniques often require high transmission power to achieve desired coverage and signal quality. By using AIS to focus the transmitted signal in the desired direction, beamforming can lead to energy-efficient communication, reducing power consumption and extending battery life in wireless devices. The reconfigurability of AIS allows for dynamic adaptation to changing environmental conditions. By employing adaptive beamforming techniques, the AIS can respond to variations in channel conditions, mobility of users, and interference sources in real-time, ensuring optimal communication performance. In dense urban environments or areas with a high number of communication devices, interference can severely degrade the quality of communication. AIS-enabled beamforming can help create nulls in the radiation pattern towards interfering sources, effectively managing co-channel interference. Beamforming with AIS can be strategically used to increase the capacity of wireless networks by focusing resources towards active users,

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reducing interference, and maximizing the reuse of the available spectrum.

The scope of applying beamforming techniques to Adaptive Intelligent Surfaces (AIS) is broad and encompasses various aspects of wireless communication system optimization and enhancement. This includes theoretical concepts, algorithm design, practical implementation, and real-world applications. The scope further extends to addressing challenges and identifying future research directions in this evolving field..

Adaptive Intelligent Surface

Adaptive Intelligent Surfaces (AIS) are advanced technology platforms that revolutionize wireless communication by enabling dynamic control over electromagnetic wave propagation. AIS consist of planar surfaces comprising a multitude of tiny, reconfigurable elements. These elements are capable of altering their electromagnetic properties, such as phase, amplitude, and polarization, in response to control signals. By manipulating these properties, AIS can effectively reshape and redirect incident waves, optimizing communication performance in various scenarios.

AIS exploits the concept of wavefront manipulation. When electromagnetic waves impinge on the surface, the reconfigurable elements adjust their properties to influence the reflected and transmitted waves. By controlling the phase and amplitude of the elements, AIS can constructively or destructively interfere with incident waves, leading to directed beams or nulls in specific directions.[5]

The phase of an electromagnetic wave determines its position within its cycle. AIS uses phase control to modify the relative timing of the wavefronts across its surface. By introducing controlled phase shifts, AIS can steer the direction of the reflected or transmitted waves, effectively altering the propagation path. The amplitude of an electromagnetic wave corresponds to its strength. By adjusting the amplitude of individual elements across the surface, AIS can regulate the intensity of the reflected or transmitted wave in different directions. This allows for the creation of varying radiation patterns. AIS can also modify the polarization state of the reflected or transmitted waves. This principle is particularly useful in scenarios where polarization diversity is important, such as in multi-polarized antennas and cross-polarized communication systems. AIS adaptability is a cornerstone principle. The elements' properties are adjusted in response to real-time feedback from sensors, channel conditions, and communication objectives. This dynamic adaptation ensures that AIS maintains optimal performance in changing environments. By manipulating wavefronts, phase, amplitude, and polarization, AIS can create desirable signal paths. These paths can enhance the signal strength, extend coverage to challenging areas, and mitigate interference, all contributing to improved communication quality.

Adaptive Intelligent Surfaces (AIS) are composed of several key components that work together to enable their unique functionality of manipulating electromagnetic waves. These components are carefully designed to facilitate real-time control over the reflection, absorption, and transmission of incident waves, thus optimizing wireless communication performance. Here are the primary components and the structure of AIS:

A. Unit Cells:

Sub-Wavelength Elements: The fundamental building blocks of AIS are the sub-wavelength-sized elements, which can include antennas, phase shifters, and varactors. These elements are usually placed in a regular array on the surface.

Tunable Properties: Each sub-wavelength element is equipped with tunable electronic components that allow dynamic adjustment of its electromagnetic properties, such as phase, amplitude, and polarization.

B. Control and Communication Interface:

Central Controller: AIS is typically controlled by a central controller, which communicates with individual unit cells to adjust their properties.

Communication Channel: The communication interface facilitates the exchange of control signals and feedback information between the central controller and the unit cells

C. Sensors and Feedback Mechanisms:

Environment Sensors: AIS often incorporates sensors to collect real-time data about the communication environment, including channel conditions, interference sources, and user locations.

Feedback Loop: The feedback loop provides the central controller with crucial information about the current state of the communication environment, enabling adaptive adjustments.

D. Signal Processing Module:

Algorithms and Optimization: The signal processing module implements various beamforming algorithms, optimization strategies, and adaptive control policies based on the feedback received from sensors.

Real-Time Adaptation: This module ensures that the AIS can dynamically adapt to changing channel conditions, user mobility, and interference sources in real-time.

E. *Deployment Structure:*

Planar Surface: AIS is deployed as a planar surface or sheet, often integrated into walls, ceilings, or facades of buildings or structures.

Array Layout: The sub-wavelength elements are organized in a carefully designed array layout, which determines the overall capabilities of the AIS in terms of beam steering, polarization manipulation, and coverage extension.

F. *Power Supply and Connectivity:*

Power Source: AIS requires a power supply to operate its tunable elements and communication interfaces.

Connectivity: Communication interfaces are connected to the central controller and sensors through wired or wireless connectivity.

G. *Adaptive Control Mechanisms:*

Feedback-Driven Adaptation: AIS dynamically adjusts the properties of its sub-wavelength elements based on feedback from sensors, optimizing the electromagnetic properties for improved communication performance.

Optimization Algorithms: Complex optimization algorithms process feedback data and modify the AIS design to meet specific communication goals, including reducing interference or increasing signal strength.

Beamforming
Conventional beamforming is a foundational technique in antenna array systems that focuses transmitted or received electromagnetic waves in a required direction. This technique is widely used in various applications, including wireless communication, radar systems, and sonar systems. Unlike modern adaptive beamforming methods, conventional beamforming does not consider dynamic adjustments based on feedback; instead, it relies on fixed weights assigned to individual antenna elements.

H. *Principles of Conventional Beamforming:[11][12]*

Conventional beamforming operates based on the principles of phase and amplitude control across an array of antenna elements

Phase Control: By introducing specific phase shifts to the signals transmitted or received by individual antenna elements, conventional beamforming ensures that the waves they emit or receive add constructively in the desired direction. This results in reinforcement of the signal in the target direction while causing destructive interference in other directions.

Amplitude Control: In addition to phase shifts, conventional beamforming may adjust the amplitudes of individual antenna elements to achieve a desired radiation pattern. Amplifying or attenuating certain elements contributes to the desired signal enhancement in the intended direction.

The steps involved in implementing conventional beamforming are as follows:

i. **Array Geometry:** A linear, planar, or other geometric arrangement of antenna elements is defined.
ii. **Desired Direction:** The target direction for focusing the beam is determined based on the application requirements.
iii. **Array Factor Calculation:** The array factor, which describes the complex combination of phase and amplitude for every antenna element, is computed for the desired direction.
iv. **Weight Assignment:** Each antenna element is assigned a complex weight that corresponds to the calculated array factor for the desired direction.
v. **Signal Combination**: The signals from all antenna elements are combined with their respective weights. The combined signal is then transmitted or processed for reception.
vi. **Beam Steering:** The combined effect of phase and amplitude adjustments results in the main lobe of the radiation pattern being steered toward the desired direction.

Advantages and Limitations: Advantages of conventional beamforming include its simplicity and ease of implementation. It's computationally less intensive compared to adaptive beamforming techniques, making it suitable for real-time applications with limited processing resources. However, conventional beamforming has limitations in scenarios with dynamic channel conditions, interference, and multipath propagation. It cannot adapt to changing conditions and lacks the ability to nullify interference sources or optimize signal quality in real-time.

Conventional beamforming finds applications in scenarios where the environment is relatively static and well-characterized, such as Simple communication systems, Directional point-to-point links, Sonar systems,Basic radar systems

I. *Analog Beamforming with Adaptive Intelligent Surfaces (AIS)*

Analog beamforming is a beamforming technique that employs phase shifts in the analog domain to steer transmitted or received signals in a desired direction. When combined with Adaptive Intelligent Surfaces (AIS), analog beamforming offers a powerful approach to enhance wireless communication systems by leveraging the reconfigurable properties of AIS to optimize signal propagation.Principles of Analog Beamforming with AIS.

Phase Manipulation: Analog beamforming with AIS involves adjusting the phase of the signals reflected by the intelligent surface's elements. By controlling the phase shifts across the surface, the reflected waves constructively interfere in the desired direction and destructively interfere in other directions.

AIS Reconfigurability: AIS elements can dynamically adjust their phase response based on control signals. This reconfigurability allows for real-time optimization of the reflected wavefront to achieve the desired beam steering. Analog Beamforming with Adaptive Intelligent Surfaces havr following Procedure.

i. **Feedback Collection:** The AIS system collects feedback from sensors about the current communication environment, including channel conditions, interference sources, and user locations.

ii. **Desired Direction:** Based on the feedback, the AIS system determines the optimal direction in which to focus the beam.

iii. **Phase Calculation:** The required phase shift for each AIS element is calculated to achieve beam steering toward the desired direction.

iv. **Control Signal Generation:** The calculated phase shifts are converted into control signals that are sent to the individual AIS elements.

v. **Phase Adjustment:** Each AIS element adjusts its phase response based on the received control signal.

vi. Signal Reflection: Incident signals are reflected off the AIS surface with the adjusted phase shifts produced by the elements.

vii. **Beam Steering:** The combined effect of the phase adjustments in the reflected signals results in the formation of a main lobe in the desired direction, steering the beam toward that location.

Advantages:

Simple Implementation: Analog beamforming is simpler to implement than digital beamforming, requiring fewer hardware components and lower computational resources.

Low Latency: Analog beamforming operates in real-time with low latency, making it suitable for applications that require immediate response.

Energy Efficiency: Analog beamforming is more energy-efficient compared to digital beamforming techniques, as it avoids the need for power-intensive digital-to-analog and analog-to-digital conversions.

Cost-Effectiveness: The simplified hardware and processing requirements make analog beamforming a cost-effective solution for improving communication performance.

Challenges:

Limited Adaptability: Analog beamforming lacks the adaptability of digital beamforming methods since it cannot dynamically adjust to changing channel conditions and interference sources.

Interference Management: Analog beamforming may struggle to handle complex interference scenarios, which can impact communication quality.

Applications:

Analog beamforming with AIS finds applications in scenarios where real-time adaptability is not a critical requirement, and the benefits of beamforming can be achieved using the reconfigurable capabilities of AIS:

i. Point-to-point communication links

ii. Fixed infrastructure deployments

iii. Coverage extension to specific areas

Overall, analog beamforming with AIS offers a practical solution for enhancing communication systems by leveraging the reconfigurable properties of AIS while maintaining a simpler and energy-efficient hardware setup.

J. Digital Beamforming with Adaptive Intelligent Surfaces (AIS)

Digital beamforming is a sophisticated beamforming technique that involves manipulating the phase and amplitude of signals in the digital domain before transmission or after reception. When combined with Adaptive Intelligent Surfaces (AIS), digital beamforming provides a highly adaptable and advanced approach to optimize wireless communication systems by harnessing the reconfigurable properties of AIS.

Principles of Digital Beamforming with AIS:

i. **Digital Processing:** Digital beamforming processes the signals digitally before or after they are transmitted or received. This processing involves adjusting the phase and amplitude of each signal sample.

ii. **AIS Reconfigurability:** AIS elements can adjust their phase response based on control signals. This adaptability allows for real-time optimization of signal propagation to achieve beam steering and other communication objectives.

Procedure:

i. **Feedback Collection**: The AIS system gathers feedback from sensors to understand the current communication environment, including channel conditions, interference sources, and user locations.

ii. **Desired Direction:** Based on the feedback, the AIS system determines the optimal direction in which to focus the beam.

iii. **Digital Signal Processing:** The collected signals are processed digitally to adjust their phase and amplitude. This processing is based on algorithms that optimize the beamforming objectives.

iv. **Control Signal Generation:** The calculated phase and amplitude adjustments are translated into control signals for the individual AIS elements.

v. **Phase and Amplitude Adjustment:** Each AIS element adjusts its phase and amplitude responses according to the received control signals.

vi. **Signal Reflection:** The adjusted signals are reflected off the AIS surface, forming a coherent beam in the required direction.

vii. **Beam Steering:** The combined effect of the digital processing and phase adjustments in the reflected signals results in the formation of a main lobe in the desired direction, steering the beam accordingly.

Advantages:

i. **Adaptability:** Digital beamforming with AIS offers high adaptability to changing channel conditions, interference, and user mobility, making it suitable for dynamic environments.

ii. **Interference Management:** Digital beamforming can handle complex interference scenarios by dynamically nullifying or suppressing interfering signals.

iii. **Optimal Signal Control:** The digital nature of this technique enables precise control over the signal characteristics, leading to improved communication quality.

iv. **Multiple Beams:** Digital beamforming can create multiple beams simultaneously, allowing communication with multiple users or points of interest.

Challenges:

i. **Computational Complexity:** Digital beamforming involves complex signal processing operations, which can be computationally intensive and require substantial processing power.

ii. **Higher Power Consumption:** Compared to analog beamforming, digital beamforming may consume more power due to the need for digital signal processing and high-speed data converters.

Applications:

Digital beamforming with AIS is particularly well-suited for scenarios where real-time adaptability and advanced control are crucial:

- Cellular networks, especially in 5G and beyond, where dynamic beamforming can optimize connectivity for rapidly changing user positions and data demands.
- Multi-user communication environments where beams can be formed towards multiple users simultaneously.
- Environments with dense interference sources where adaptive nulling of interfering signals is essential.

In summary, digital beamforming with AIS offers a sophisticated solution for optimizing wireless communication systems by leveraging the adaptability of AIS along with the precision and control provided by digital signal processing. This combination enables effective beamforming in dynamic and complex communication scenarios.

K. Intelligent Reflecting Surfaces (IRS)-Assisted Beamforming[16][21]

Intelligent Reflecting Surface is emerged as a novel technology that enhances wireless communication systems by utilizing reconfigurable metasurfaces to control and manipulate electromagnetic waves. When combined with beamforming techniques, IRS can significantly improve signal quality, coverage, and capacity, offering a new paradigm known as IRS-assisted beamforming.

PRINCIPLES OF IRS-ASSISTED BEAMFORMING:

i. **IRS Functionality:** Intelligent Reflecting Surfaces composed of passive elements that can modify the phase and amplitude of incident electromagnetic waves. These elements, often arranged in a regular grid, act as "smart mirrors" that reflect and redirect signals.

ii. **Beamforming Interaction:** In IRS-assisted beamforming, the signals from a transmitter travel to the IRS, where they are reflected and reconfigured before reaching the receiver. The IRS effectively shapes the propagation environment, optimizing the signal path.

Procedure:

i. **Signal Transmission:** The transmitter sends signals towards the IRS.

ii. **Signal Reflection:** The IRS elements adjust their phase and amplitude responses to manipulate the reflected signals. This adjustment is based on real-time feedback from sensors, such as channel conditions and interference levels.

iii. **Reflected Signal Manipulation:** The reflected signals interfere with each other constructively or destructively, resulting in the desired beamforming effect. The IRS is configured to create beams, nulls, or other radiation patterns that optimize signal reception at the receiver.

iv. **Signal Reception:** The reconfigured signals reach the receiver with enhanced quality due to the optimized signal path created by the IRS.

Advantages:

i. **Enhanced Signal Quality:** IRS-assisted beamforming can significantly enhance signal strength, particularly in challenging environments with obstacles, reflections, or attenuation.

ii. **Coverage Extension:** By shaping the propagation environment, IRS can extend coverage to areas that were previously difficult to reach.

iii. **Interference Management:** IRS can nullify or redirect interfering signals, improving signal-to-interference ratios and communication quality.

iv. **Energy Efficiency:** IRS does not require active transmission; it operates by modifying the reflection of existing signals. This can lead to energy savings.

v. **Multiple Users:** IRS can be dynamically configured to support multiple users by creating individual beams for each user.

Challenges:

i. **Control Complexity:** Efficient control algorithms are required to dynamically adjust IRS elements for optimal beamforming, especially in scenarios with multiple users and changing channel conditions.

ii. **Hardware Complexity:** Implementing a large-scale IRS with numerous elements demands careful design and deployment to ensure effective signal manipulation.

iii. **Channel Estimation:** Accurate feedback from the environment is necessary for effective IRS-assisted beamforming. However, obtaining accurate channel information can be challenging in practice.

Applications:

IRS-assisted beamforming has broad applications across various communication scenarios:

- Indoor environments where signals need to penetrate obstacles and provide uniform coverage.
- 5G and beyond networks that require higher data rates, capacity, and spectral efficiency.
- Internet of Things (IoT) deployments where reliable connectivity is needed in diverse locations.
- Millimeter-wave and terahertz communication systems that benefit from focused beams and precise signal control.
- Satellite and space communications, where optimizing signal paths can enhance link performance.

In summary, IRS-assisted beamforming combines the benefits of beamforming techniques with the reconfigurable capabilities of Intelligent Reflecting Surfaces, offering a powerful solution to enhance wireless communication systems in terms of coverage, signal quality, and interference management. This technology holds significant promise for the evolution of next-generation communication networks.

Yunaben chen et al [1] propose that the double fading that the signal on RIS-aided vehicular communications experiences and reconfigurable intelligent surface (RIS)-assisted vehicular communications are two major obstacles. acquiring channel state information (CSI) is made intractably difficult by cascaded links and high mobility. This work presents a solution to these issues: the active reconfigurable intelligent omni-surface (RIOS), a novel kind of RIS that amplifies and transmits the incoming signal at the same time, instead of only reflecting it as in the case of a passive reflectingonly RIS. Active loading support every component of RIOS. They have considered the application of an active RIOS to mitigate the impacts of double fading in a vehicular communication system. Specifically, the active RIOS is installed on the vehicle's window to enhance communication for occupants and bystanders. In order to minimize the transmit power of the base station (BS), the authors jointly optimize the transmit precoding matrix at the BS and RIOS coefficient matrices, depending only on a partial comprehension of the large-scale CSI. First, an effective transmission protocol is offered to benefit from the high active RIOS beamforming gain with minimal channel training cost by appropriately varying the time-scale of CSI collecting. As a result, the frequency of updates to the channel information will be greatly decreased. The examined resource allocation problem is then tackled by two methods, the constrained stochastic successive convex approximation (CSSCA)-based algorithm and the alternating optimization (AO)-based algorithm, whose benefits and drawbacks are examined in turn. Simulation results demonstrate that active RIOS greatly enhances performance and validates the model's validity and resilience.

Peng xu et al [2] in their work Examine the reconfigurable intelligent surface (RIS) technique for physical-layer authentication in point-to-point wireless networks. The Internet of Things (IoT) is being marketed as the essential platform for enabling safe transmission and huge connections. Since there is no direct link between legitimate and illegitimate IoT devices and the access point, we benefit from RIS by considering two main secure performance criteria. Their main goal was to evaluate the secrecy performance of wireless communication systems with RIS assistance that function safely while there are IoT devices around that are listening. RIS is situated in this instance between the access point and the It is compatible with valid devices and designed to enhance link security. They first gave analytical results on the possibility of secrecy outage in order to define secure system performance indicators. A closer look at the secrecy rate follows. It's interesting to note that both the number of RIS metasurface elements and the average signal-to-noise ratio at the source need to be under control in order to enhance system performance. By comparing the results of Monte Carlo simulation and analytical calculations, they validated the derived expressions.

Zengchaun Chen et al [3] in their work regarding RIS assisted multigroup multicast system propose Reconfigurable Intelligent Surface (RIS), which has the ability to regulate and optimize wireless channels, is promising in improving the Multigroup Multicast System's (MMS) capacity. Ergodic rate (ER) is a statistical concept that is well-understood by statistical channel state information (CSI). Suitable metric to evaluate the RIS-assisted MMS's efficacy. In this work, authors obtained the closed-form expression of ER for each group based on statistical CSI and show that the ratio of elements on the RIS to group members affects a group's outage rate. The issue of maximizing the system's ER is then simulated using mixed integer nonlinear programming. it is not convex. Authors suggest an alternate optimization approach to tackle it using the gradient descent-based power allocation technique and the heuristic subcarrier assignment algorithm. Simulation results show that proposed method in RIS-assisted MMS can achieve a significant gain in ER compared with the random subcarrier assignment plan with average power allocation and the case without RIS.

Zhaungzhaung Cui et al [4] proposed that studying the effects of reconfigurable intelligent surfaces (RISs) is essential because when beamforming is used at the transmitter, only a portion of them may be active.geometry.

The purpose of this letter is to assess RIS geometry, which includes linear (1D), planar (2D), and cylindrical (3D) structures.Authors first determine the signal-to-noise ratio (SNR) and outage probability of various RIS topologies' effective illuminated elements. The best RIS location is then looked into in terms of balancing active area versus received power while taking near-field propagation into account. The benefit of RIS geometric compactness is quantified by numerical results, which also provide the relevant ranges.

The article by Yeliang Liu et al [5] examines physical layer security (PLS) in RIS-assisted reconfigurable intelligent surfaces. MIMOME channels stand for multiple-input, multiple-output, multiple-antenna. The problem that the secrecy rate cannot be computed if the instantaneous channel state information (CSI) of the eavesdropper is the unknown is not addressed by current studies. Phase shifter optimization for PLS enhancement is impossible without the secrecy rate expression, even with beamforming. To address these problems, we first introduce the

RIS-assisted PLS metric as the expression of secrecy outage probability for any beamforming vector and phase shifter matrix. This metric is computed based on the statistical CSI of the eavesdropper. Next, they have used the expression to formulate the secrecy outage probability mini-mization issue, which is solved via alternating beamforming vector and phase shift matrix optimization. To minimize computational complexity, the suggested alternating optimization (AO) approach might be made simpler for single-antenna transmitters or legitimate receivers. Lastly, compared to the existing RIS-assisted PLS systems, it is shown that the secrecy outage probability is much lower using the suggested approaches.

Alexandros A. et al [6] offers a quantitative assessment of the eavesdropping-resistant physical layer security capabilities of wireless systems backed by reconfigurable intelligent surfaces (RIS). In particular, author obtain a flexible closed-form definition for the ergodic secrecy capacity (ESC) that is adaptable to different RIS sizes and fading kinds. It is assumed that the channels follow independent mixture Gamma (MG) distributions between the transmitter (TX) and the legitimate receiver (RIS), the RIS and the eavesdropper, and the TX and the RIS. MG can represent a variety of well-known distributions, including the Gaussian, Rayleigh, Nakagami-m, Rice, and others. The results demonstrate that even when the diversity order of valid links grows, the ESC advantage reduces as RIS size increases.

Feihong Chen et al [9] proposed that a secure wireless system with a reconfigurable intelligent surface (RIS) has recently sparked a lot of controversy. Research on the assessment of security risks from the illicit RIS (IRIS) used by nefarious eavesdroppers is still lacking, though. The signal leakage caused by IRIS in a typical RIS-enhanced mmWave multiple-input multiple-output (MIMO) wiretap system is examined in this paper. Authors begin by highlighting the drawbacks and difficulties of IRIS with regard to system secrecy rate (SR) competition. The presence of IRIS makes it more challenging to identify eavesdropper behaviors, making a global solution to the SR competition problem impractical. Therefore, to mitigate the security degradation brought on by IRIS, Authors suggest an interference scheme based on artificial noise (AN). To generate more AN, the transmit precoder, receiver combiner, and RIS discrete phase shifts are specifically designed in concert by utilizing the interpolation search method and the sparsity of mmWave channels. Simulation results show the non-negligible SR degradation brought on by IRIS and validate the proposed scheme's effective security enhancement. Additionally, Authors strongly examine particular system variables that must be taken into account to effectively combat IRIS, particularly when it is strong.

Georgious Mylonopoulose et al [11] talks about improvement of SNR of the wireless communication system using RIS, authors examined the issue of user localization. with a live reconfigurable intelligent surface (RIS) in a single-user and single-cell scenario. perspectives on the design of A location estimator based on multiple signal transmissions and particle filtering (PF) is suggested. RIS configuration and on the power split between the base station (BS) and the active RIS are illustrated. The aforementioned algorithm makes use of extra features and degrees of freedom that are not accessible when a passive RIS is used. Extensive numerical simulations demonstrate the effectiveness of the suggested approach in comparison to a solution based on passive RIS and support analytical findings. Theoretical performance bounds are also derived.

Jiang Liu et al [15] in their work concluded that the next generation of wireless communications is expected to use reconfigurable intelligent surfaces (RISs), which are an emerging technology. In this paper, authors take into consideration a network with multiple inputs and multiple outputs, where each base station Using a RIS with N re-configurable elements, assist user equipment. Author describe the disruption at a single piece of user equipment that is a result of the signal that its non-serving (interfering) RIS emits. Using the Rayleigh fading theory author investigate the corresponding interference-to-noise ratio (INR) for the channels using the assumption that N has large values, and demonstrate how a Chi-Square random variable (RV) and an RV that is roughly modeled by a Gamma distribution combine to form the INR. Additionally, it is demonstrated that the INR's amount of fading is equal.

Findings, Lacunas And Future Scope

Table I given below the details of findings and future directions of various literature reviewed. Beamforming using adaptive intelligent surfaces will play a pivotal role in enhancing the performance of 6G networks and beyond. By manipulating electromagnetic waves intelligently, these surfaces can mitigate interference, improve signal strength, and extend coverage, leading to faster and more reliable wireless communication. The technology can be applied to satellite communication systems, improving data transmission rates and reducing latency. This will be particularly important as demand for high-speed internet access in remote areas and during disaster recovery efforts continues to grow. As the Internet of Things (IoT) and smart city initiatives gain traction, adaptive intelligent surfaces can help optimize wireless connectivity for a multitude of devices and sensors, enhancing the efficiency and effectiveness of these systems. Beamforming can be employed to improve communication between autonomous vehicles, infrastructure, and control centers, ensuring reliable and low-latency data exchange critical for safe self-driving operations. In the medical field, adaptive intelligent surfaces can enhance the quality of medical imaging by reducing interference and improving signal quality. This can lead to more accurate diagnoses and better patient care. Radar and communication systems used in defense applications can benefit greatly from adaptive intelligent surfaces. They can enhance stealth capabilities, improve surveillance, and increase the overall efficiency of military operations. These surfaces can be used to enhance remote environmental monitoring, allowing for more precise data collection in areas such as agriculture, forestry, and climate research.

Following are the challenges in the employment of AIS assisted sytems

Designing and optimizing the configuration of adaptive intelligent surfaces can be a complex task. Determining the optimal arrangement of reflecting elements and adjusting their properties in real-time to achieve desired beamforming objectives can be computationally intensive and require sophisticated algorithms. The operation of adaptive intelligent surfaces typically involves active components such as phase shifters or tunable metasurfaces. Ensuring that these components are energy-efficient is a challenge, especially in scenarios where the surfaces need to be powered autonomously, such as in IoT devices or remote sensing applications. Retrofitting adaptive intelligent surfaces into existing infrastructure, such as buildings or communication towers, can be logistically challenging. Compatibility issues, space constraints, and retrofit costs must be considered. Real-world environments are dynamic, with changing channel conditions, interference, and obstacles. Adaptive intelligent surfaces need to adapt quickly to these changes to maintain effective beamforming, which can be a significant challenge.

Developing and deploying adaptive intelligent surfaces can be expensive. The cost of manufacturing and deploying the necessary materials and components can be a barrier to widespread adoption, especially in resource-constrained settings. Coexistence with other wireless systems and devices can lead to interference issues. Managing interference and ensuring that adaptive surfaces do not disrupt existing wireless networks is crucial. Regulatory approval and standardization processes can be lengthy and complex. Ensuring that adaptive intelligent surface technology complies with relevant regulations and industry standards is essential for its adoption. Like any connected technology, adaptive intelligent surfaces are vulnerable to security breaches and privacy concerns. Protecting the surfaces from unauthorized access and ensuring the privacy of users' data is a critical challenge. Building expertise in the design, deployment, and maintenance of adaptive intelligent surfaces is essential but requires specialized knowledge and training. Bridging the skills gap in this emerging field is a challenge.

Sr. No.	**First Author**	**Type**	**Year**	**Technique Used**	**Results /Findings**	**Lacuna/ Drawbacks/Future Scope**
1	Yuanbin Chen	IEEE	Oct-22	Active Reconfigurable Intelligent Omni-surfaces	Alternating optimization (AO) Constrained stochastic successive convex approximation algorithms are used to mitigate double fading. RIOS perform better as compared to normal intelligent surfaces	AO algorithm cannot guarantee uniform performance
2	Peng Xu	IEEE	Dec-20	Reconfigurable intelligent surfaces	Ergodic secrecy rate scales with $\log_2 N$ for both colluding and non colluding eavesdroppers	Performance is verified only for single users may vary for MIMO system
3	Zengchaun Chen	IEEE	Apr-23	RIS assisted multigroup multicast system	Outage rate of group is determined by ratio between number of elements on RIS and number of users in group	Outage rate is dependent on N, to improve performance N must be increased
4	Zhaungzhaung Cui	IEEE	May-23	Effect of RIS geometry on performance	Planner (2D) and Cylindrical(3D) RIS can be used for longer and shorter distance respectively. They give wider and narrower beamwidth respectively	Linear (1D) and 2D RIS are less preffered because 3D is more compact
5	Yiliang Liu	IEEE	Feb-23	RIS assisted MIMO multiple atenna eavesdropper system	Secrecy outage probability is reduced using alternating optimization technique	Algorithm not verified for multiple user and multiple stream scenario
6	Alexandros A.	IEEE	2023	RIS aided wireless system	As the RIS size increases the ergodic secrecy capacity gain decreases	Limited improvements in physical layer secrecy after certain size of RIS
7	Saber Hassauna	IEEE	2023	RIS aided system with EMI consideration	EMI increases as we increase the size of the RIS	Results need to be verified for MIMO
8	Tatiana Valera	IEEE	2023	Beamforming using 1 bit topology	Multi object beam steering is achieved using 1-bit shift registers	1 bit phase shifter gives 4 dB loss as compared to conventional phase shifters
9	Feihong Chen	IEEE	2023	Secure mmWave MIMO communication with respect to illegal RIS	Artificial noise based interference scheme is used to limit the effect of illegal RIS	The system may degrade if illegal RIS is made smart
10	Zipeng Wang	IEEE	2021	RADAR cross section based receiver power model	Received power is related to distance from transmitter/receiver to RIS, the angle between Tx-RAS-Rx triangle and area of the reflecting element	Model fails for far field case and if angles are too large

11	Georgious Mylonopoulose	IEEE	2022	Active RIS	Use of active RIS improves overall performance in terms of SNR	Results are only verified for single user single cell
12	Povel Tulupov	IEEE	Jul-22	RIS	Coverage increases by 25% with the use of dynamic surface	Smart model can be developed that will meet speed and energy efficiency requirements
13	Lugi Chen	IEEE	2022	Cross deployment of active and passive RIS	Cross deployment of active and passive RIS meet the beneficial maximization of capital and running cost	The complexity is doubled
14	Guorgov Straticlacy	IEEE	2021	RIS	As the size of RIS increases the received power increases	Future scope is to improve received power with limited number of elements
15	Jiang Liu	IEEE	2021	Interference analysis for RIS	Amount of fading is independent of number of elements	Fading is independent of N so if power is enhanced with small N SNR can be improved
16	Jun Wang	IEEE	Aug-21	SNR upper bound maximization(SUM) and Genetic SNR maximization (GSM)	The performance is significantly improved using SUM and GSM	Phase shifters are modified performance can be further improved by applying advancements in beamforming

TABLE I. FINDINGS LACUNAS AND FUTURE SCOPE OF REVIEWED LITERATURE

Conclusion

In conclusion, beamforming using adaptive intelligent surfaces is a cutting-edge technology with tremendous potential for transforming various industries and applications. Its ability to manipulate electromagnetic waves with precision opens up new possibilities for improving wireless communication, radar systems, and more. As research and development in this field continue, we can anticipate breakthroughs in materials science, algorithms, and hardware design that will further enhance the capabilities of adaptive intelligent surfaces. The technology's ability to adapt to changing environmental conditions and user requirements makes it a versatile solution for the evolving demands of modern society. In the coming years, we can look forward to witnessing the integration of this technology into our daily lives, from faster and more reliable internet connectivity to safer and more efficient transportation systems. The future of beamforming using adaptive intelligent surfaces is indeed bright, and its potential to revolutionize the way we connect, communicate, and interact with the world is boundless

References

[1] Yuanbin Chen, Ying Wang, Zhaocheng Wang And Ping Zhang, "Robust Beamforming For Active Reconfigurable Intelligent Omni-Surface In Vehicular Communications," IEEE Journal On Selected Areas In Communications, Vol. 40, No. 10, October 2022.

[2] Peng Xu, Gaojie Chen, Senior Gaofeng Pan, Senior And Marco Di Renzo, "Ergodic Secrecy Rate Of RIS-Assisted Communication Systems In The Presence Of Discrete Phase Shifts And Multiple Eavesdroppers," IEEE Wireless Communications Letters ,December 2020

[3] Zhengchuan Chen , Li Chen, Student Zhong Tian , Min Wang , Yunjian Jia , And Linglong Dai "Ergodic Rate Of Reconfigurable Intelligent Surface-Assisted Multigroup Multicast System," IEEE Transactions On Vehicular Technology, Vol. 72, No. 4, April 2023.

[4] Zhuangzhuang Cui, And Sofie Pollin, " Impact Of Reconfigurable Intelligent Surface Geometry On Communication Performance," IEEE Wireless Communications Letters, Vol. 12, No. 5, May 2023.

[5] Amirmasood Bagheri, Mahmood Safaei , Ali Araghi, S. M. Mahdi Shahabi1 , Fan Wang , Mohsen Khalily , And

Rahim Tafazolli 1 , “Mathematical Model and Real-World Demonstration of Multi-Beam and Wide-Beam Reconfigurable Intelligent Surface”

[6] Yiliang Liu , Zhou Su , Senior Chi Zhang, and Hsiao-Hwa Chen , “Minimization of Secrecy Outage Probability in Reconfigurable Intelligent Surface-Assisted MIMOME System,” IEEE Transactions On Wireless Communications, Vol. 22, No. 2, February 2023.

[7] Alexandros-Apostolos A. Boulogeorgos, and Angeliki Alexiou, “On the Ergodic Secrecy Capacity of Reconfigurable Intelligent Surface Aided Wireless Systems Under Mixture Gamma Fading,”2023 IEEE Wireless Communications And Networking Conference (WCNC).

[8] Saber Hassouna , Muhammad Ali Jamshed , Masood Ur-Rehman , Muhammad Ali Imran , and Qammer H. Abbasi, “Reconfigurable Intelligent Surfaces Aided Wireless Communications with Electromagnetic Interference”

[9] Tatiana Valera, Satheesh B. Venkatakrishnan, Arjuna Madanayake, and John L. Volakis, “Reconfigurable Intelligent Surfaces for Adaptive Nulling and Beam Steering Using 1-bit Topology”

[10] Feihong Chen , Hancheng L , Yazheng Wang , Chenwu Zhang, “Secure mmWave MIMO Communication against Signal Leakage When Meeting Illegal Reconfigurable Intelligent Surface,” IEEE Wireless Communication And Networking Conference (WCNC).

[11] Zhiwei fu,Xiaopeng zou,Yunqi liao, “A Brief Review and Comparison Between Transmitarray Antennas, Reflectarray Antennas and Reconfigurable Intelligent Surfaces,” IEEE Conference On Telecommunication, Optics And Computer Science (TOCS).

[12]]Xiaopeng zou,Junhao Yao,Kwok L.chung, “A Comparative Study Between Reconfigurable Intelligent Surface and Reflectarray Antenna,” IEEE 5th International Conference Information and Communication Technology(ICEICT).

[13] Zipeng Wang , Li Tan , Haifan Yin , Kai Wang , Xilong Pei , David Gesbert, “ A Received Power Model for Reconfigurable Intelligent Surface and Measurement-based Validations,” IEEE 22nd International Workshop on Singal Processing Advances in Wireless Communications (SPAWC).

[14] Georgios Mylonopoulos , Carmen D’Andrea and Stefano Buzzi, “Active Reconfigurable Intelligent Surfaces for User Localization in mmWave MIMO Systems,” IEEE 23 International Workshop Om Signal Processing Advancements In Wireless Communication.

[15] Nguyen Minh Tran, Muhammad Miftahul Amri, Je Hyeon Park, Ghafar Ramadhan Faqih, Dong In Kim, Kae Won Choi, “Beam Splitting Technique for Reconfigurable Intelligent Surface-Aided Simultaneous Wireless Information and Power Transfer Applications,” IEEE Information Theory Workshop (ITW)

[16] Pavel Tulupov, Boris Sorokin, Anatoliy Korolev, “Coverage Impact Of Reconfigurable Intelligent Surfaces In 6G Mobile Networks,” Proc. of the International Conference on Electrical, Computer and Energy Technologies (ICECET 2022) 20-22 July 2022, Prague- Czech Republic.

[17] Luqi Chen , Kwok L. Chung, Guoming Lai , Junhao Yao , Xiaopeng Zou , Xin Cheng , Kangtai Zheng , Yingsong L, “Cross Deployment of Active and Passive Reconfigurable Intelligent Surfaces (RISs) for NextGeneration Communications,” IEEE 5th International Conference on Electronic Information and Communication Technology (ICEICT).

[18] Giorgos Stratidakis, Sotiris Droulias, and Angeliki Alexiou, “Impact of Reconfigurable Intelligent Surface size on beamforming efficiency,” IEEE, 32nd Annual International Symposium On Personel,Indoor And Mobile Radio Communication.

[19] Jiang Liu, Xuewen Qian, and Marco Di Renzo, “Interference Analysis In Reconfigurable Intelligent Surface-Assisted Multiple-Input Multiple-Output Systems,” ICASSP-2021 IEEE International Conference On Acoustics, Speech And Signal Processing.

[20] Jun Wang , Graduate Student Ying-Chang Liang , Jingon Joung , Senior Xiaojun Yuan , Senior and Xinguo Wang, “Joint Beamforming and Reconfigurable Intelligent Surface Design for Two-Way Relay Networks,” IEEE Transactions On Communications, Vol. 69, No. 8, August 2021.

[21] Mohamed A. ElMossallamy, Student Hongliang Zhang, Lingyang Song, Karim G. Seddik, Senior Zhu Han, and Geoffrey Ye Li, “Reconfigurable Intelligent Surfaces for Wireless Communications: Principles, Challenges, and Opportunities,” IEEE Transactions on Cognitive Communications and Networking 2020