Spectrum of Engineering Sciences
ISSN (e) 3007-3138 (p) 3007-312X Volume 3, Issue 7, 2025

RECONFIGURABLE INTELLIGENT SURFACE (RIS): STRENGTHS, WEAKNESSES, OPPORTUNITIES AND THREATS

Haneef Hamza[1] Arbab Talha [2]Dr. Sadiq Ullah[3] Umer Suvaid Ahmed [4]

[1]*University of Engineering and Technology, Mardan.*

[2]*University of Engineering and Technology, Mardan*

[3] *Chairman of Telecommunication Engineering Department UET, Mardan.*

[4]*University of Engineering and Technology , Mardan*

haneefhamza@ymail.com [1] arbabtalhah@gmail.com [2] umersuvaid@gmail.com[4]

DOI: https://doi.org/10.5281/zenodo.16108438

Keywords

Reconfigurable Intelligent Surface (RIS), Sixth generation mobile system (6G), Wireless communication, Smart cities, Internet of things (IoT).

Article History

Received on 08 May 2025

Accepted on 08 June 2025

Published on 16 July 2025

Corresponding Author: *

Haneef Hamza

Abstract

Reconfigurable Intelligent Surfaces (RIS) have emerged as a promising enabler of next-generation wireless networks, particularly in the evolution toward 6G communication systems. Unlike conventional active technologies such as massive MIMO and relay stations, RIS comprises passive or semi-passive reflective elements capable of dynamically manipulating incident electromagnetic waves in terms of phase, amplitude, frequency or polarization. This capability transforms the wireless environment into a programmable medium, leading to enhanced coverage, energy efficiency, and communication reliability with minimal power consumption. This paper presents a comprehensive SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis of RIS technology, identifying its core advantages such as signal coverage enhancement, low-cost deployment, sustainability, and scalability as well as its current limitations, including passive gain constraints, control complexity, and dependence on accurate channel state information. It also explores the expansive opportunities of RIS when integrated with artificial intelligence, particularly in smart cities, IoT networks, and rural connectivity. The paper also critically assesses external threats such as technological competition, security vulnerabilities, and regulatory challenges. Through this strategic analysis provides actionable insights for researchers, engineers, and policymakers to guide the effective integration of RIS into future wireless infrastructure.

1. Introduction to Reconfigurable Intelligent Surfaces (RISs)

One of the revolutionary technologies in wireless communications, especially in the emergence of the 6G next generation networks, is Reconfigurable Intelligent Surfaces (RIS). RIS is formed by large surfaces full of a solid set of passive or semi-passive reflecting elements that can dynamically change the phase, amplitude, or polarization of the electromagnetic waves that impinge on them. Unlike conventional antennas, these surfaces do not produce signals but sensibly reflect the same to increase the propagation of the signals, energy efficiency, and overall communication efficiency [1]. Structurally, RIS units are usually formed from programmable meta-surfaces, a controller, and integrated circuits for real-time manipulation of electromagnetic responses [2]. These surfaces can be positioned tactically on walls, ceilings, or building facades so that a smart wireless environment is created within which signals could be manipulated and redirected to maximize coverage and performance. The passive or even quasi-passive design of RIS is one of the major advantages of RIS over traditional communication technologies like the massive Multiple Input Multiple Output (MIMO) systems, repeaters, etc. While MIMO uses active transmission and consumes much power, RIS can deliver comparable coverage amplification without bringing signals to the boil and introducing noise [3]. This makes RIS much more energy efficient and affordable, especially in a highly populated city or desolate areas with scarce infrastructure.

The RIS is ready to transform the applications in 6G networks due to the ability to create smart radio environments with adaptivity, sustainability, and high-programmability opportunities [4]. RIS, in the Internet of Things framework, can enhance and allow low-power wide-area network connectivity for billions of devices with negligible interference [5]. It is also critical for the emerging use cases such as smart buildings, autonomous transportation, and industrial automation [6]. Although RIS promises to do well, it is still in its initial research and application process. Hence, it is important to examine its technological opportunities, dangers, and boundaries strategically. In order to evaluate the capability of RIS technology for use in the real world, a SWOT analysis gives strategic guidance to policymakers, engineers, and stakeholders who need to integrate future research and development activities to address the market and infrastructure demands.

2. Strengths of RIS

Reconfigurable Intelligent Surfaces (RIS) provide a paradigm shift in wireless communication since they allow the wireless environment to be controlled in a programmable manner. RIS differs from conventional technologies that use active components to manage signal transmission and reception. It utilizes a passive or semi-passive layer to efficiently and intelligently reflect an incident electromagnetic wave. This new approach opens up several latent strengths, making RIS an extremely appealing solution for future wireless systems [7]. Energy efficiency is one of the strongest points of RIS. In legacy wireless infrastructure, convolutional, relay, or massive MIMO systems require active amplification and signal processing, thus considerably increasing energy consumption. On the contrary, RIS does not require active radio-frequency (RF) chains and power-hungry components. Reflective parts of RIS, whose design is commonly based on meta surfaces or liquid crystal-based materials, require very little energy to modify phase shifts; hence, the technology is very energy-conservative [8]. Another advantage lies in cost-effectiveness. Because RIS has no power amplifiers, RF chains, and complex hardware, manufacturing, deploying, and servicing are naturally cheaper than active devices such as relay stations or base stations. This allows for cost-conscious deployments, especially in rural or not-well-developed areas, where a lack of funds keeps the infrastructure expansion at bay [9].

The RIS technology is also very programmable regarding the dynamic manipulation of beamforming and directionality of signals. RIS can adjust to changing network scenarios and propagate paths using integrated control units and real-time configurations. Such adaptability becomes particularly important in a mobile or signal quality-variable environment, such as urban/indoor [10]. Programmability means that RIS can program the wireless environment itself, instead of changing the transmitter or receiver, which is a powerful change from old paradigms. One more vital strength of RIS is its scalability. Passive RIS panels allow for dense, wide-scale fielding without significant energy and heat anxiety. These panels can be mounted easily on walls, windows, and ceilings to bring big-scale changes in signal coverage with no impact on space and infrastructure [11].

The RIS improves a network's capacity and overall range by providing a custom-made propagation environment [12]. This results in better user experience, less latency, and increased spectral efficiency. RIS encourages environment-friendly or green communication. RIS reduces the requirement of power-hungry components and optimizes the propagation of the existing signals, thus helping to cut carbon emissions and running costs. This goes very well with sustainability goals in the world and the increased demand for eco-conscious solutions in technological fields [13].

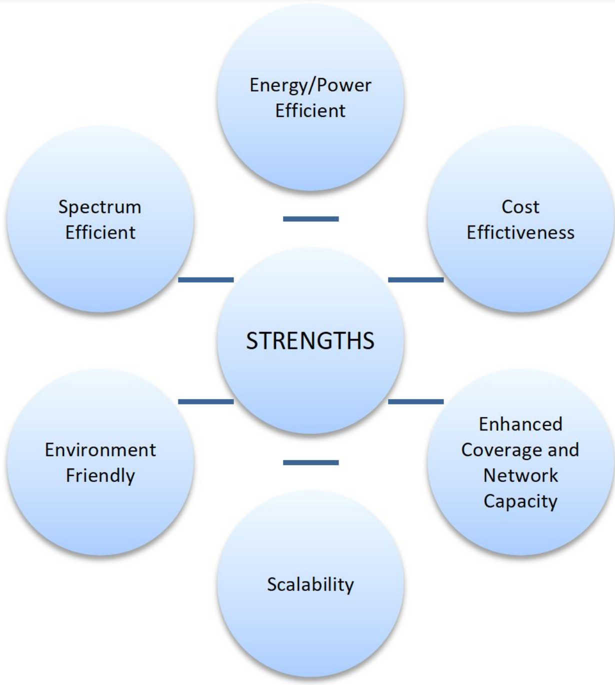

Figure 1: Block diagram of Strengths of Reconfigurable Intelligent Surface

3. Weaknesses of RIS

Although the Reconfigurable Intelligent Surfaces (RIS) offer attractive benefits, several technical and practical barriers prevent a widespread implementation of this technology today. These weaknesses must be amended before RIS can grow and become a credible and trustworthy technology in future wireless networks. One of the major issues is the small gain because it is passive. RIS elements do not have the same function of amplifying signals as active relays or base stations do; they just reflect signals. This implies that the fundamental limitation of RIS's capability of enhancing the signal exists. The reflected signal level is usually far less effective than active solutions can provide when paid for, especially in terms of length coverage or a path loss-prone environment [14]. As a result, RIS may need huge surface areas or accurate placement to perform effectively, which can be difficult in the real world. RIS is also faced with complex control and coordination. As pointed out, actuating the behavior of hundreds or thousands of reflective elements is not a trivial task that entails refined control algorithms and live processing. This complexity is further heightened regarding system size and extent of user mobility, making it hard for the systems to use responsive and stable control architectures [15]. Also, it is possible to face difficulty in using current hardware to support low-latency reconfiguration for all the elements in a scalable and power-efficient approach [16]. Dependence on correct Channel State Information (CSI) is another major limitation. The performance of RIS largely depends on the accurate knowledge of the wireless channel between the base station, RIS, and user equipment [17].

Degradation in performance in fast-varying settings is also a limiting factor to RIS applications. With inherent latency in sensing and reconfiguration, RIS may not be able to respond quickly in very dynamic scenarios, such as vehicular communications or drones. For such cases, the traditional adaptive antennas or active MIMO systems are still better than RIS in response and reliability [18]. No standardization and a lack of regulatory frameworks make RIS deployment more complex. RIS, a relatively new technology, has not been fully harmonized with the existing wireless communication standards. This slows down commercial system integration and affects legacy infrastructure interoperability [19].

These issues involving electromagnetic compatibility, security, and spectrum management are unanswered. Lastly, physical vulnerability and alignment sensitivity are other issues [20]. RIS must move from experimental setups to scalable commercial solutions to overcome these limitations, especially for passive gain, control complexity and CSI dependency [21].

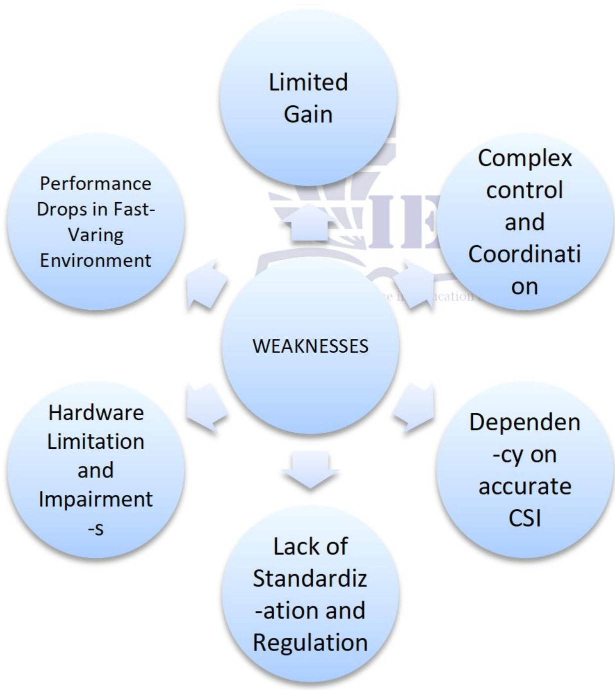

Figure 2: Block diagram of Weaknesses of Reconfigurable Intelligent Surface

4. Opportunities of RIS

Reconfigurable Intelligent Surfaces (RIS) can generate many opportunities that can greatly improve the performance of future wireless communication systems and some others fields also. As the World prepares for 6G, RIS emerges as the core facilitator of intelligent radio environments (IREs) networks where the environment gets programmable and receptive to communication requirements [22]. One of the most promising opportunity for RIS is its integration into sixth generation (6G) mobile system. It differs from previous generations, which focused on higher data rates and low latency, to 6G, which utilizes ambient intelligence, network adaptability, and energy efficiency [23]. RIS is consistent with these objectives since it allows on-demand steering of signals, the suppression of interference, and environment-aware communication. In 6G architectures, RIS can control the propagation environment at will, creating a dynamic and self-optimizing communication scenario [24]. RIS will also greatly benefit from integrating Artificial Intelligence (AI) and Machine Learning (ML). The application of AI is beneficial to optimize RIS configuration in real-time, multi-user interference, and prediction of wireless channel conditions. Machine learning models can be taught to predict changes in channel states and update RIS phase shifts accordingly in very mobile or dense environments [25]. This combination of RIS and AI forms adaptive beamforming systems that are more sensitive and efficient than traditional rule-based control. Looking within the scope of urban planning, RIS provides possibilities for revolution in smart cities and smart buildings [26].

Another important opportunity is to provide low-cost rural deployment. Conventional cellular infrastructure is sometimes expensive and poses a significant challenge to implement in distant or poor regions. Because it is passive and inexpensive, RIS can provide signal coverage in such areas without requiring large-scale base stations/fiber backhaul [27]. This can be used to close the digital gap as it ensures that the internet is available in the underserved communities. RIS also has potential in cross-industry uses outside of telecommunication. RIS can help vehicular communications in automotive systems, as signal strengths and reliability can be enhanced along highways or urban roads. In healthcare, RIS can help provide high-reliability, low-latency connectivity required for telemedicine or wireless monitoring of patients inside smart hospitals [28]. Industries such as industrial automation, logistics, and defense can also profit from this flexible technology [29].

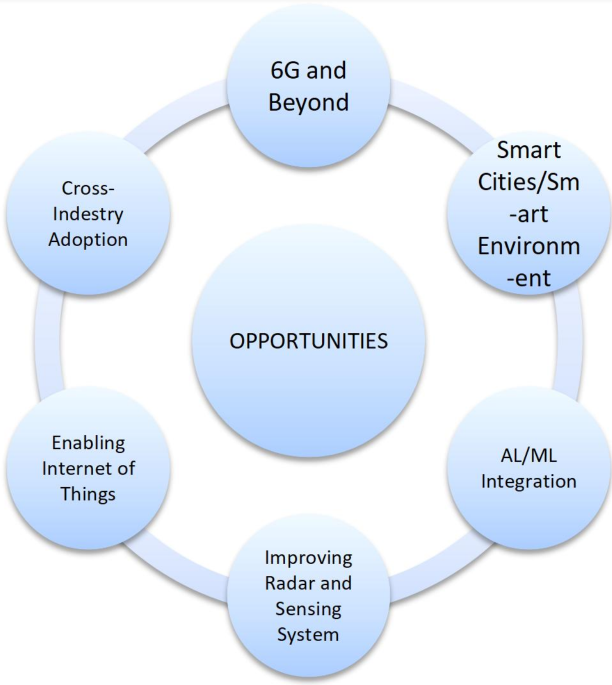

Figure 3: Block diagram of Opportunities of Reconfigurable Intelligent Surface

5. Threats of RIS

Despite the promising developments and prospects of Reconfigurable Intelligent Surfaces (RIS), the widespread adoption of this technology is confronted by several external risks and difficulties. These threats are spread across technical, industrial, legal, and strategic domains. They must be removed to enable RIS to grow into a useful, scalable, and secure part of future communication networks [30]. One of the main threats to RIS is from the rival emerging technologies, including massive MIMO (Multiple-Input Multiple-Output), millimeter-wave (mmWave), and terahertz communications. Such technologies are more mature and are being rolled out commercially, particularly in the advanced 5G and pre-6 G world [31]. The fact is that massive MIMO, for example, can provide high capacity and multiplexing gains without the complexity of external reflective surfaces [32]. Privacy and security risks related to RIS are another problem. With the way RIS alters the transmission of electromagnetic waves, there is a possibility of malicious use like signal spoofing, jamming, and unauthorized signal manipulation [33]. RIS might reflect sensitive data unwittingly in the directions of unintended recipients or might open exploitable backdoors in secure communication channels [34].

The control units that deal with RIS configuration can be attacked by cybercriminals, putting vast network segments at risk [4]. A significant challenge is inherent in integrating RIS with pre-existing wireless infrastructure. Intelligent environmental surfaces were not considered when the current network architecture and protocols were made [35].

In industry opposition from the existing telecom stakeholders can delay the adoption of RIS. Telecommunication providers prefer established supply chains, chains that return on investment (ROI), and industry backup logics [36]. To persuade such stakeholders to shift directions towards a relatively untested way of doing things, such as RIS adaptation, may be hard, particularly in capital-intensive areas where risk-aversion is significant [37]. RIS also suffers an imminent threat of technological obsolescence. The speed of development of wireless solutions will be such that new, efficient solutions may appear before RIS is commercialized [38]. If the competing technologies provide similar or better performance without RIS's complexity, the technology will be marginalized or relegated to niche applications [39]. Finally, patent disagreements and licensing contests can hamper the development and deployment of RIS. Consequently, institutions and firms rush to patent RIS-related innovations, leading to overlapping claims and intellectual property conflicts, posing legal obstructions to manufacturers and innovators [40].

Figure 4: Block diagram of Threats of Reconfigurable Intelligent Surface

Table 1: Comparative SWOT Analysis of Reconfigurable Intelligent Surfaces (RIS)

Strengths	Weaknesses (in comparison)
Passive design saves energy	Cannot amplify signals due to passive nature
Cost-effective compared to active technologies	Complex control and coordination of reflective elements
Programmable for dynamic beamforming	Depends heavily on accurate Channel State Information (CSI)
Scalable and modular deployment	Difficult to integrate with existing wireless infrastructure
Enhances coverage in non-line-of-sight (NLOS) areas	Performance reduces in mobile or fast-changing environments
Supports green and sustainable communication	Physically vulnerable to damage, misalignment, or obstruction
Opportunities	**Threats (in comparison)**
Key role in 6G and intelligent radio environments	Competing technologies like massive MIMO and THz communication
Integration with AI/ML for smart beamforming	Requires high computation; may introduce latency or system load
Useful in smart cities, smart buildings, and IoT systems	Existing infrastructure may not support RIS integration easily
Low-cost connectivity for rural and remote areas	Lack of global standards and regulations can delay deployment
Cross-industry use: automotive, healthcare, factories	Security risks such as signal spoofing or hacking of RIS control units
Hybrid use with MIMO or relay systems for reliability	Rapid tech advancement could make RIS obsolete before full adoption
Aligns with sustainability and energy-saving goals	Patent and licensing issues may increase legal and commercial hurdles

Conclusion

Reconfigurable Intelligent Surfaces (RIS) represent a groundbreaking advancement in wireless communication, offering the potential to reshape how radio environments are utilized, controlled, and optimized in the era of 6G and beyond. By enabling passive or semi-passive manipulation of electromagnetic waves, RIS provides a sustainable, energy-efficient, and cost-effective alternative to traditional active communication technologies. The conducted SWOT analysis highlights that RIS excels in programmability, scalability, and alignment with global sustainability goals. Critical challenges such as limited signal amplification, complex control requirements, reliance on precise channel state information, and the absence of standardized regulatory frameworks must be addressed before large-scale deployment can be realized.

Despite these limitations, the technology's integration with artificial intelligence and machine learning opens pathways for intelligent, adaptive, and resilient wireless networks. Moreover, RIS holds promise across diverse domains including smart cities, rural connectivity, healthcare, transportation, and industrial automation. Nonetheless, external threats from competing technologies, security concerns, and legal uncertainties may delay or hinder widespread adoption. To harness the full potential of RIS, focused research, cross-industry collaboration, and proactive policy development are essential. With strategic efforts, RIS can become a cornerstone of future communication systems, enabling intelligent and sustainable connectivity across global networks.

References

[1] Ahmed M, Raza S, Soofi AA, Khan F, Khan WU, Xu F, Chatzinotas S, Dobre OA, Han Z. A survey on reconfigurable intelligent surfaces assisted multi-access edge computing networks: State of the art and future challenges. Computer Science Review. 2024 Nov 1;54:100668.

[2] Ahmed M, Xu F, Wahid A, Ali K, Mirza MA, Khan W, Dev K, Hassan SA, Han Z. A comprehensive survey of artificial intelligence advances in RIS-assisted wireless networks. Authorea Preprints. 2024 Aug.

[3] Bariah L, Mohjazi L, Abumarshoud H, Selim B, Muhaidat S, Tatipamula M, Imran MA, Haas H. RIS-assisted space-air-ground integrated networks: New horizons for flexible access and connectivity. IEEE Network. 2022 Sep 26;37(3):118-25.

[4] Björnson E, Wymeersch H, Matthiesen B, Popovski P, Sanguinetti L, De Carvalho E. Reconfigurable intelligent surfaces: A signal processing perspective with wireless applications. IEEE Signal Processing Magazine. 2022 Feb 24;39(2):135-58.

[5] Cao X, Yang B, Huang C, Yuen C, Di Renzo M, Han Z, Niyato D, Poor HV, Hanzo L. AI-assisted MAC for reconfigurable intelligent-surface-aided wireless networks: Challenges and opportunities. IEEE Communications Magazine. 2021 Jun;59(6):21-7.

[6] Chataut R, Akl R. Massive MIMO systems for 5G and beyond networks—overview, recent trends, challenges, and future research direction. Sensors. 2020 May 12;20(10):2753.

[7] Chiaraviglio L, Elzanaty A, Alouini MS. Health risks associated with 5G exposure: A view from the communications engineering perspective. IEEE Open Journal of the Communications Society. 2021 Aug 19;2:2131-79.

[8] Das SK, Benkhelifa F, Sun Y, Abumarshoud H, Abbasi QH, Imran MA, Mohjazi L. Comprehensive review on ML-based RIS-enhanced IoT systems: basics, research progress and future challenges. Computer Networks. 2023 Apr 1;224:109581.

[9] Di Renzo M, Zappone A, Debbah M, Alouini MS, Yuen C, De Rosny J, Tretyakov S. Smart radio environments empowered by reconfigurable intelligent surfaces: How it works, state of research, and the road ahead. IEEE journal on selected areas in communications. 2020 Jul 14;38(11):2450-525.

[10] Du H, Kang J, Niyato D, Zhang J, Kim DI. Reconfigurable intelligent surface-aided joint radar and covert communications: Fundamentals, optimization, and challenges. IEEE Vehicular Technology Magazine. 2022 May 4;17(3):54-64.

[11] ElMossallamy MA, Zhang H, Song L, Seddik KG, Han Z, Li GY. Reconfigurable intelligent surfaces for wireless communications: Principles, challenges, and opportunities. IEEE Transactions on Cognitive Communications and Networking. 2020 May 5;6(3):990-1002.

[12] Liu Y, Liu X, Mu X, Hou T, Xu J, Di Renzo M, Al-Dhahir N. Reconfigurable intelligent surfaces: Principles and opportunities. IEEE communications surveys & tutorials. 2021 May 5;23(3):1546-77.

[13] Gong S, Lu X, Hoang DT, Niyato D, Shu L, Kim DI, Liang YC. Toward smart wireless communications via intelligent reflecting surfaces: A contemporary survey. IEEE Communications Surveys & Tutorials. 2020 Jun 22;22(4):2283-314.

[14] Hemanth A, Umamaheswari K, Pogaku AC, Do DT, Lee BM. Outage performance analysis of reconfigurable intelligent surfaces-aided NOMA under presence of hardware impairment. IEEE Access. 2020 Nov 24;8:212156-65.

[15] Hong S, Pan C, Ren H, Wang K, Nallanathan A. Artificial-noise-aided secure MIMO wireless communications via intelligent reflecting surface. IEEE Transactions on Communications. 2020 Sep 21;68(12):7851-66.

[16] Hu J, Zhang H, Di B, Li L, Bian K, Song L, Li Y, Han Z, Poor HV. Reconfigurable intelligent surface based RF sensing: Design, optimization, and implementation. IEEE

Journal on Selected Areas in Communications. 2020 Jul 3;38(11):2700-16.

[17] Mishra D, Johansson H. Channel estimation and low-complexity beamforming design for passive intelligent surface assisted MISO wireless energy transfer. InICASSP 2019-2019 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP) 2019 May 12 (pp. 4659-4663). IEEE.

[18] Jia S, Yuan X, Liang YC. Reconfigurable intelligent surfaces for energy efficiency in D2D communication network. IEEE Wireless Communications Letters. 2020 Dec 22;10(3):683-7.

[19] Liu, R.; Alexandropoulos, G.C.; Wu, Q.; Jian, M.; Liu, Y. How can reconfigurable intelligent surfaces drive 5G-advanced wireless networks: A standardization perspective. In Proceedings of the 2022 IEEE/CIC International Conference on Communications in China (ICCC Workshops), Foshan, China, 11–13 August 2022.

[20] Khoshafa MH, Maraqa O, Moualeu JM, Aboagye S, Ngatched TM, Ahmed MH, Gadallah Y, Di Renzo M. RIS-assisted physical layer security in emerging RF and optical wireless communication systems: A comprehensive survey. IEEE Communications Surveys & Tutorials. 2024 Oct 28.

[21] Liang Z, Cai G, He J, Kaddoum G, Huang C, Debbah M. RIS-enabled anti-interference in LoRa systems. IEEE Transactions on Communications. 2024 May 16.

[22] Liu J, Zhang H. Throughput Optimization in Aerial RIS-Assisted Networks with 3D Imperfect Reflection. IEEE Transactions on Vehicular Technology. 2025 Feb 19.

[23] Liu R, Wu Q, Di Renzo M, Yuan Y. A path to smart radio environments: An industrial viewpoint on reconfigurable intelligent surfaces. IEEE Wireless Communications. 2022 Jan 12;29(1):202-8.

[24] Basar E, Alexandropoulos GC, Liu Y, Wu Q, Jin S, Yuen C, Dobre OA, Schober R. Reconfigurable intelligent surfaces for 6G: Emerging hardware architectures, applications, and open challenges. IEEE Vehicular Technology Magazine. 2024 Jul 11.

[25] Long W, Chen R, Moretti M, Zhang W, Li J. A promising technology for 6G wireless networks: Intelligent reflecting surface. Journal of Communications and Information Networks. 2021 Mar 26;6(1):1-6.

[26] Long, R., Zeng, Y., & Zhang, R. (2020). "Fully Passive Intelligent Reflecting Surface With Discrete Phase Shifts: Channel Estimation and Passive Beamforming." *IEEE Transactions on Wireless Communications*.

[27] Mei W, Zhang R. Distributed beam training for intelligent reflecting surface enabled multi-hop routing. IEEE Wireless Communications Letters. 2021 Aug 13;10(11):2489-93.

[28] Pan Q, Wu J, Nebhen J, Bashir AK, Su Y, Li J. Artificial intelligence-based energy efficient communication system for intelligent reflecting surface-driven vanets. IEEE transactions on intelligent transportation systems. 2022 Mar 4;23(10):19714-26.

[29] Putra GD, Dedeoglu V, Kanhere SS, Jurdak R. Toward blockchain-based trust and reputation management for trustworthy 6G networks. IEEE Network. 2022 Oct 14;36(4):112-9.

[30] Rathore RS, Sangwan S, Kaiwartya O, Aggarwal G. Green Communication for Next‐Generation Wireless Systems: Optimization Strategies, Challenges, Solutions, and Future Aspects. Wireless Communications and Mobile Computing. 2021;2021(1):5528584.

[31] Ray PP. A perspective on 6G: Requirement, technology, enablers, challenges and future road map. Journal of Systems Architecture. 2021 Sep 1;118:102180.

[32] Sejan MA, Rahman MH, Shin BS, Oh JH, You YH, Song HK. Machine learning for intelligent-reflecting-surface-based wireless communication towards 6G: A review. Sensors. 2022 Jul 20;22(14):5405.

[33] Siri JG, Fernando CA, De Silva SN. Nanotechnology and protection of intellectual property: emerging trends. Recent Patents on Nanotechnology. 2020 Dec 1;14(4):307-27..

[34] Tang W, Chen MZ, Chen X, Dai JY, Han Y, Di Renzo M, Zeng Y, Jin S, Cheng Q, Cui TJ. Wireless communications with reconfigurable intelligent surface: Path loss modeling and experimental measurement. IEEE transactions on wireless communications. 2020 Sep 25;20(1):421-39.

[35] Wang P, Fang J, Zhang W, Chen Z, Li H, Zhang W. Beam training and alignment for RIS-assisted millimeter-wave systems: State of the art and beyond. IEEE wireless communications. 2022 May 9;29(6):64-71.

[36] Wang Z, Liu L, Cui S. Channel estimation for intelligent reflecting surface assisted multiuser communications: Framework, algorithms, and analysis. IEEE transactions on wireless communications. 2020 Jun 30;19(10):6607-20.

[37] Wang Z, Shi Y, Zhou Y, Zhou H, Zhang N. Wireless-powered over-the-air computation in intelligent reflecting surface-aided IoT networks. IEEE Internet of Things Journal. 2020 Aug 10;8(3):1585-98.

[38] Wu Q, Zhang S, Zheng B, You C, Zhang R. Intelligent reflecting surface-aided wireless communications: A tutorial. IEEE

transactions on communications. 2021 Jan 18;69(5):3313-51.

[39] Zhao X, Jian M, Chen Y, Zhao Y, Mu L. Reconfigurable intelligent surfaces for 6G: Engineering challenges and the road ahead. Intelligent and Converged Networks. 2025 Mar;6(1):53-81.

[40] Chen C, Luo J, Shen D, Xu Z, Xiong R. Achieving Low Queueing Latency in Time-Slotted LoRa Networks. In2024 27th International Conference on Computer Supported Cooperative Work in Design (CSCWD) 2024 May 8 (pp. 3237-3242). IEEE.