A Comprehensive Systematic Review of Reflection Intelligent Surfaces (RIS) in Free-Space Optical (FSO) Systems: Atmospheric Impacts and Advanced Communication Strategies

Shahrizan Mohd Razali[1,*], Razali Ngah[1], Samir A. Al-Gailani[1], Zaid Ahmed Shamsan[2], Norhanis Aida Mohd Nor[3]

1 Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310, Johor Bahru, Johor, Malaysia
2 Department of Electrical Engineering, College of Engineering, Imam Mohammad Ibn Saud Islamic University (IMSIU), Riyadh, 11432, Saudi Arabia
3 Kulliyyah of Engineering, International Islamic University Malaysia, Jalan Gombak, 53100 Kuala Lumpur, Malaysia

ARTICLE INFO	ABSTRACT
	Free Space Optic (FSO) communication systems offer high data rates and cost efficiency. Nevertheless, their performance is significantly hindered by adverse weather conditions like fog, rain, and snow, which result in scattering, absorption, and attenuation of optical signals. To address these challenges, integrating Reflection Intelligent Surface (RIS) technology is seen as a promising solution to enhance the performance and reliability of FSO systems. This review focuses on the impact of weather conditions on RIS-assisted FSO communication systems, using a comprehensive analysis based on the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) framework. Scholarly articles from Scopus, Web of Science (WoS), and Institute of Electrical and Electronics Engineers (IEEE), published between 2024 and 2026, were analysed, yielding 34 relevant studies. The findings were organised into three key themes: (1) RIS in FSO systems, (2) Effects of Atmospheric and Environmental Conditions on RIS and FSO Systems, and (3) Advanced Communication Strategies in Optical Networks. The analysis highlights that RIS technology can mitigate some of the detrimental effects of weather on FSO systems by dynamically adjusting the phase and direction of optical signals, improving Signal-to-Noise Ratio (SNR), Bit Error Rate (BER), and data throughput under moderate weather conditions. However, extreme weather events still present significant challenges that RIS alone cannot fully overcome. In conclusion, while RIS significantly enhances FSO system performance in mild-to-moderate weather conditions, extreme conditions necessitate further research into innovative designs and adaptive control mechanisms that can provide robust communication across all weather scenarios.

1. Introduction

The increasing demand for high-capacity, low-latency communication systems has

driven significant research into advanced wireless technologies [1], [2]. Free Space Optics (FSO) has emerged as a promising solution for high-speed data transmission, especially in urban environments where the Radio Frequency (RF) spectrum is limited [3]. Other than that, FSO communication leverages the line-of-sight transmission of optical signals through the atmosphere, offering several advantages, such as high bandwidth, immunity to electromagnetic interference, and secure data transfer [4], [5]. However, the performance of FSO systems is highly susceptible to environmental factors, particularly weather conditions such as fog, rain, snow, and turbulence, which can severely degrade the signal quality [4], [5] (figure 1). In parallel with the evolution of FSO, the concept of Reflection Intelligent Surface (RIS)-assisted communication has gained considerable attention to enhance the reliability and efficiency of wireless networks [4], [6]. RIS technology involves the use of programmable surfaces, typically composed of a large array of passive reflective elements, which can be adjusted to control the phase, amplitude, and direction of incoming electromagnetic waves. By intelligently manipulating these properties, RIS can effectively mitigate signal blockages, improve signal strength, and extend the coverage area, making it a valuable addition to FSO systems [7].
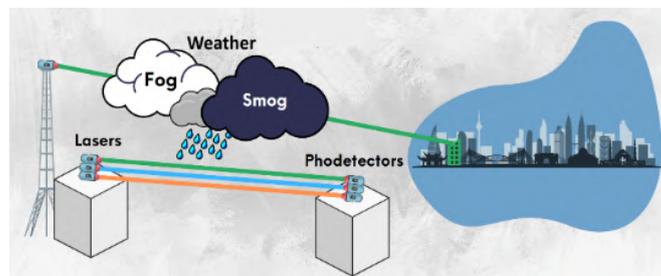

Fig. 1. FSO Communication System [8]

The integration of RIS into FSO communication systems holds significant potential to overcome some of the inherent limitations of FSO, particularly in adverse weather conditions [9]–[15]. Moreover, RIS can be strategically deployed to optimize the path of optical signals by passing obstructions and compensating for signal degradation caused by scattering and absorption in the atmosphere [9], [14], [16]–[18]. This synergy between FSO and RIS could lead to more resilient communication systems that maintain high performance even in challenging environmental scenarios [12], [15], [19]. Despite its promising advantages, the performance of RIS-assisted FSO systems under varying weather conditions remains a critical area of investigation [20]–[22]. Note that different weather phenomena affect the propagation of optical signals in distinct ways, necessitating a comprehensive analysis to understand their impact on the overall system performance [14], [20], [21]. For instance, fog can cause severe attenuation of the optical signal due to scattering, while rain and snow primarily contribute to absorption and scattering [11], [12], [20], [21]. Additionally, atmospheric turbulence can induce random fluctuations in the signal phase and amplitude, further complicating the transmission [6], [11], [12], [15], [20], [21]

This research addresses key questions about the impact of weather on RIS-assisted FSO communication systems. It examines weather-induced issues, the implementation of adaptive strategies, and their effects on system performance in both real-world and simulated environments. Additionally, it explores the challenges of long-term, large-scale deployments under diverse weather conditions and potential solutions. By analyzing how RIS mitigates weather-related impairments, this study aims to optimize FSO systems for

real-world use, contributing to the development of resilient, high-performance next-generation communication networks.

2. Literature review

The impact of weather on FSO RIS-assisted communication systems has received significant attention, with research highlighting key challenges like fog, rain, and turbulence that degrade signal quality [23]. While FSO links offer high-speed, secure communication, they rely on a direct Line of Sight (LoS) and are greatly affected by adverse weather [24], [25]. RIS can enhance signal quality by intelligently reflecting it towards the receiver, significantly improving the error performance analytical and simulation studies confirm that RIS-assisted MIMO/FSO substantially lowers outage and bit error rates under turbulence and misalignment [9], [18]. This integration can mitigate weather-related issues, increasing robustness (Simbarashe et al., 2025). Additionally, RIS has been introduced in hybrid FSO systems with RF or other links to further address these challenges and improve secrecy and reliability in mixed RF/FSO networks [26]. Research also highlights RIS's potential in Satellite–Aerial–Ground–type architectures and quantum FSO networks, enhancing reliability by overcoming blockages, cloud cover and turbulence, particularly in hybrid or RIS-assisted FSO/RF and quantum setups that dynamically adjust or optimize paths for stable connections [11].
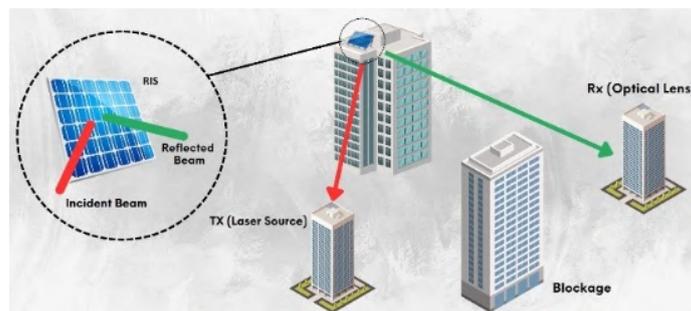

Fig. 2. FSO Communication Systems Enhanced by RIS [8]

Recent studies have focused on the impact of weather on hybrid FSO/THz systems, particularly the performance of RIS-assisted hybrid systems under weather-induced impairments like fog and atmospheric turbulence [27], [28]. The performance of a hybrid FSO/THz system is analyzed using Maximal Ratio Combining (MRC) and Selection Combining (SC), showing that RIS technology significantly improves system resilience by optimizing the Signal-to-Noise Ratio (SNR) and reducing outage probability, even under severe atmospheric conditions [27], [28]. Integrating RIS into mixed THz/FSO systems enhances reliability and mitigates the adverse effects of fog and turbulence, common in FSO systems. These studies confirm RIS's critical role in maintaining communication performance during weather-related disturbances [29]. Research on RIS-assisted FSO systems focusing on atmospheric turbulence and pointing errors for smart city applications shows that RIS improves the Bit Error Rate (BER) and outage probability by compensating for signal blockages and turbulence-induced fading with closed-form expressions for these metrics [30]. Increasing RIS elements enhances system robustness against adverse weather conditions, emphasizing RIS's potential in ensuring reliable FSO communication in densely populated urban environments.

The integration of RIS with FSO systems has also been explored in multi-link configurations, where optimal placement of RIS elements plays a crucial role in system performance. [31] presents a model for a multi-link terrestrial RIS-assisted FSO system, considering key degrading factors such as pointing errors and atmospheric turbulence. Their results suggest that the optimal placement of RIS elements, particularly closer to the transmitter or receiver depending on conditions, can substantially improve system performance by mitigating channel impairments and jitter effects [31]. This study highlights the importance of strategic RIS placement in maximizing the benefits of RIS technology in FSO systems, especially under dynamic environmental conditions where weather and other factors significantly impact signal quality [32], [33]. Furthermore, [34] investigated transmission challenges in IRS-assisted FSO systems coexisting with direct FSO links and proposed schemes optimizing performance under varying weather conditions, demonstrating that RIS integration can improve system reliability by up to 40% [35]. The ability of RIS to dynamically manipulate optical signal propagation has been shown to improve average symbol error rates and overall system reliability; however, current research often relies on theoretical models with limited empirical validation, indicating a need for further practical studies and exploration of hybrid technologies and security implications in FSO channels [26], [34].In conclusion, integrating RIS into FSO systems significantly enhances their performance under adverse weather conditions, such as fog, rain, and turbulence. RIS technology mitigates signal degradation by optimizing the signal path and improving metrics like Signal Error Rate (SER), Bit Error Rate (BER), and outage probability. Additionally, strategic placement of RIS elements and advanced optimization techniques, such as machine learning, further enhance system reliability, making RIS a crucial component in maintaining robust FSO communication in challenging environmental conditions.

3. Material and methods

The PRISMA framework enhances transparency and rigor in systematic literature reviews through its four phases—identification, screening, eligibility, and data abstraction—focusing on randomized trials to reduce bias. This review used Web of Science, Scopus, and IEEE databases for comprehensive coverage. PRISMA's structured approach improves research quality and reliability.

3.1 Identification

This study employed systematic review procedures to gather relevant materials, expanding keywords using dictionaries, thesauri, encyclopaedias, and prior research. Search strings were then developed for IEEE, WoS, and Scopus databases, leading to the identification of 374 relevant papers (see Table 1).

Table 1
The Search String

Scopus	ALL (("free space optic*" OR "FSO") AND ("reflect* intelligent* surface*" OR "Intelligent* reflection* surface*" OR "reconfigure* intelligent* surface*" OR "reflect* Intelligence* Surface*" OR "Intelligence* reflect* surface*" OR "RSI" OR "IRS") AND ("weather*" OR "atmospheric*" OR "turbulence*" OR "rain*" OR "haze*")). Date of Access: February 2026
IEEE	(("free space optic" OR "FSO") AND ("reflect* intelligent surface" OR "Intelligent* reflection* surface" OR "reconfigure* intelligent surface" OR "reflect* Intelligence* Surface" OR "Intelligence* reflect* surface" OR "RSI" OR "IRS") AND ("weather" OR "atmospheric" OR "turbulence" OR "rain" OR "haze")). Date of Access: February 2026
WoS	TS= (("free space optic*" OR "FSO") AND ("reflect* intelligent* surface*" OR "Intelligent* reflection* surface*" OR "reconfigure* intelligent* surface*" OR "reflect* Intelligence* Surface*" OR "Intelligence* reflect* surface*" OR "RSI" OR "IRS") AND ("weather*" OR "atmospheric*" OR "turbulence*" OR "rain*" OR "haze*")). Date of Access: February 2026

3.2 Screening

During the screening phase, 249 duplicate publications were excluded, leaving 123 papers aligned with the research question on weather's impact on FSO RIS-assisted communication systems (see Table 2). The review focused on English-language literature from 2024 to 2026, including reviews, meta-analyses, and conference proceedings. A total of 21 publications were rejected due to duplication.

Table 2
The selection criterion is searching

Criterion	Inclusion	Exclusion
Language	English	Non-English
Timeline	2024 – 2026	< 2024
Literature type	Journal (Article)	Conference, Book, Review
Publication Stage	Final	In Press
Subject	Engineering	Besides Engineering
Keyword	Optical, RIS, FSO	others

3.3 Eligibility

In the eligibility phase, 102 articles were thoroughly reviewed, focusing on titles and key content to ensure alignment with the research objectives. 68 articles were excluded due to irrelevance or lack of full-text access, leaving 34 articles for further review.

3.4 Data Abstraction and Analysis

An integrative analysis was conducted to synthesize various quantitative research designs, focusing on data collection and theme development. Figure 3 shows the detailed analysis of 34

publications on weather effects in FSO RIS-assisted systems. The authors collaboratively developed themes, documented insights, and resolved any inconsistencies during the process.
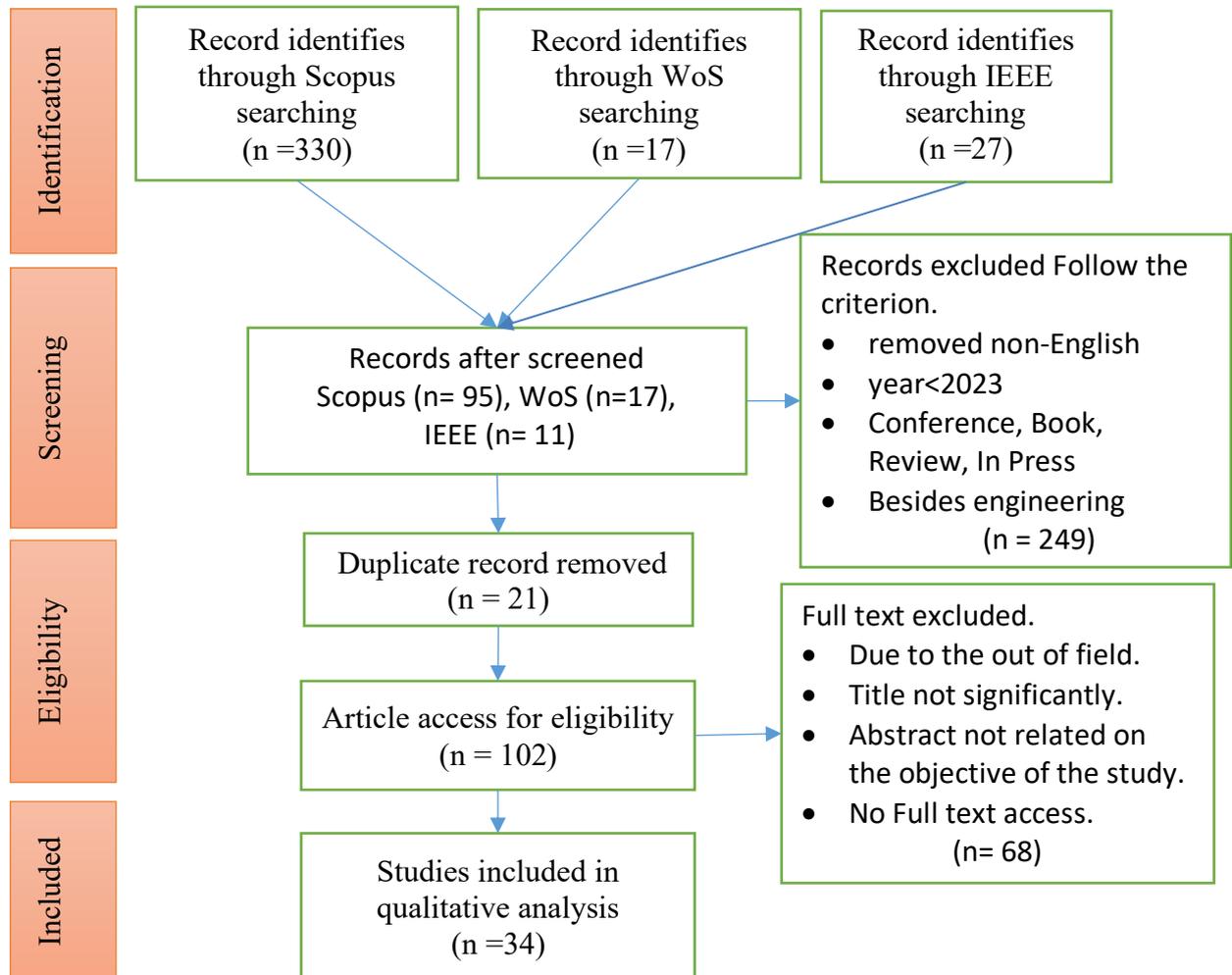

Fig. 3. Flow diagram of the proposed search (PS) study

4. Quality of Appraisal

According to the guidelines proposed by Kitchenham and Charters [36], once we had selected PSs we had to assess the quality of the research they presented and quantitatively compare them. In this study, we apply Quality Assessment (QA) from A.AbouZahra [37], which consists of five QAs for our Systematic literature review (SLR). The scoring procedure for evaluating each criterion involves three possible ratings: "Yes" (Y) with a score of 1 if the criterion is fully met, "Partly" (P) with a score of 0.5 if the criterion is somewhat met but contains some gaps or shortcomings, and "No" (N) with a score of 0 if the criterion is not met at all.

Table 3
The table outlines a Quality Assessment (QA) process used to evaluate a study based on specific criteria

Quality Assessment	Expert 1	Expert 2	Expert 3	Total Mark
Is the purpose of the study clearly stated?	Y	Y	Y	3
Is the interest and the usefulness of the work clearly presented?	Y	Y	Y	3
Is the study methodology clearly established?	Y	Y	Y	3
Are the concepts of the approach clearly defined?	Y	Y	Y	3
Is the work compared and measured with other similar work?	Y	Y	Y	3

Here's a detailed explanation:
1. Is the purpose of the study clearly stated?
   This criterion checks whether the study's objectives are clearly defined and articulated. A clear purpose helps set the direction and scope of the research.
2. Is the interest and usefulness of the work clearly presented?
   This criterion evaluates whether the study's significance and potential contributions are well-explained. It measures the relevance and impact of the research.
3. Is the study methodology clearly established?
   This assesses whether the research methodology is well-defined and appropriate for achieving the study's objectives. Clarity in methodology is crucial for the study's validity and reproducibility.
4. Are the concepts of the approach clearly defined?
   This criterion looks at whether the theoretical framework and key concepts are clearly articulated. Clear definitions are essential for understanding the study's approach.
5. Is the work compared and measured with other similar work?
   This evaluates whether the study has been benchmarked against existing research. Comparing with other studies helps position the work within the broader academic context and highlights its contributions.

Each expert independently assesses the study according to these criteria, and the scores are then totalled across all experts to determine the overall mark. For a study to be accepted for the next process, the total mark, derived from summing the scores from all three experts, must exceed 3.0. This threshold ensures that only studies meeting a certain quality standard proceed further.

5. Result and Finding

The produced themes were eventually tweaked to ensure consistency. The analysis selection was conducted by two experts specializing in communication systems, especially in FSO-RIS-assisted Communication Systems, to determine the validity of the problems. Note that the expert review phase ensures the clarity, importance, and suitability of each subtheme by establishing the domain validity of the problems. The expert review phase ensures the clarity, importance, and suitability of each subtheme by establishing the domain validity. The author also compared the findings to resolve discrepancies in the theme-creation process. Note that if any inconsistencies on the theme arose, the authors addressed them with one another.

5.1 Reflection Intelligent Surfaces (RIS) in Free-Space Optical (FSO) Systems

RIS has shown significant potential in enhancing the performance of FSO systems, particularly by mitigating the effects of atmospheric turbulence, pointing errors, and misalignments. Studies highlight the importance of RIS in improving Average Symbol Error Rate (ASER) and outage probability in turbulent conditions using advanced models such as gamma-gamma and Fisher-Snedecor F-distribution [9]. Ishida et al. (2024b) further explore the optimization of IRS placement to maximize performance by considering pointing errors and system jitter, offering valuable insights for system design [9]. Additionally, Ajam et al. (2024) propose various IRS-sharing protocols to address non-uniformity and misalignment issues in multi-link FSO systems, demonstrating the impact of IRS configurations on BER and overall system reliability [68]

The impact of atmospheric turbulence and environmental conditions on RIS-assisted FSO systems has been widely examined, with studies confirming their significance in real-world applications and showing that these systems maintain performance under adverse weather modeled by Malaga and Fisher-Snedecor distributions [48], [69]. Advanced strategies like phase-shift optimization and multihop relaying further improve system performance, enabling reliable communication across varying distances and conditions [68], [70].

5.2 Effects of Atmospheric and Environmental Conditions in Reflection Intelligent Surfaces (RIS) and Free-Space Optical (FSO) Systems

RIS significantly enhances FSO systems by mitigating atmospheric challenges like turbulence, fog, and pointing errors. Meanwhile [71] demonstrated that addressing the transmitter beam waist radius and pointing error displacement reduces the ASER in RIS-assisted FSO systems. Similarly, [72] highlighted the severe impact of atmospheric turbulence on data transmission, emphasising the challenge of maintaining reliable communication. Various studies, including those by [73] and [74], explored optimisation and error-control strategies, such as PSO and retransmission protocols, to improve FSO performance under adverse conditions. Therefore, [75] introduced SIMO techniques to mitigate jamming, verifying their effectiveness through Monte Carlo simulations.

Table 4
Summary of Results on Atmospheric and Environmental Effects in RIS and FSO Systems

Reference	Methodology	Results on Atmospheric and Environmental Conditions
[76]	Numerical simulations investigating pointing errors and atmospheric turbulence on RIS-aided FSO links using log-normal distribution for weak turbulence and SC-QAM modulation.	Atmospheric turbulence and pointing errors significantly impact the ASER, with the performance degrading with increased turbulence.
[77], [78]	Theoretical analysis of ASER using log-normal turbulence channels for FSO links with RIS. The study considers variables like link distance, transmitted power, and QAM scheme.	Atmospheric turbulence and signal attenuation result in substantial ASER degradation, particularly over long distances and with increased optical power.
[47]	Analysis of a mixed IRS-aided RF-FSO system using Nakagami-m distribution for RF and F distribution turbulence for FSO, incorporating Monte Carlo simulations.	Atmospheric turbulence and pointing errors reduce performance metrics such as BER and SNR. However, the IRS mitigates some of these adverse effects.

[79]	Investigation of the effects of environmental conditions on FSO data and power transmission under normal and turbulent conditions.	Turbulent atmospheric conditions degrade data and power transmission. Nevertheless, FSO outperforms RF communication under similar conditions.
[80]	Proposal of a PSO method for optimising UAV trajectories in FSO communications, considering atmospheric loss due to fog and pointing errors.	Atmospheric losses, particularly due to fog, create inhomogeneous media affecting laser propagation, and pointing errors exacerbate these losses. Optimised UAV trajectories reduce some of these losses.
[33]	Study of IRS-assisted UAV FSO systems affected by atmospheric turbulence, pointing errors, and jamming, using Monte Carlo simulations.	Atmospheric turbulence and pointing errors, when combined with jamming, drastically reduce system performance. Nonetheless, the IRS helps mitigate some of these effects.
[75]	Investigation of jamming impacts on RIS-assisted dual-hop FSO systems using SIMO configuration and Monte Carlo simulations.	Environmental conditions such as atmospheric turbulence, pointing errors, and jamming significantly impact the Average Bit Error Rate (ABER).

5.3 Advanced Communication Strategies in Optical Networks

RIS and hybrid FSO/RF systems have shown substantial promise in overcoming performance limitations associated with conventional FSO communication systems. [81] discuss the effectiveness of cognitive RF-FSO fronthaul assignment strategies in Cell-Free massive MIMO (CF-mMIMO) networks. The research emphasises how energy efficiency is improved by 198% in the presence of adverse weather conditions and FSO misalignment, particularly when the RF-FSO hybrid link is deployed. [82] further contribute to the field by exploring hybrid FSO/sub-THz vertical networks designed for the Internet of Vehicles (IoV). The findings underscore the importance of optimising switching techniques, showing that both soft-switching and hard-switching methods can significantly enhance performance metrics, such as outage probability and TCP throughput, especially under challenging atmospheric conditions such as rain and fog. Consequently, [83] present a similar hybrid approach by incorporating optical IRS into a dual-hop mixed FSO/RF system for Cloud Radio Access Networks (C-RAN). The results demonstrate that using polar codes and beamforming techniques significantly reduces turbulence-induced fading and misalignment errors, improving data rates and reliability, as confirmed by Monte Carlo simulations.

Environmental impediments, particularly atmospheric turbulence and adverse weather conditions, remain among the most critical challenges in maintaining signal integrity in FSO communication systems. Correspondingly, [84] propose a RIS-UAV relay-assisted hybrid FSO/RF system for Satellite Aerial-Ground Integrated Networks (SAGIN), focusing on mitigating the effects of cloud coverage and atmospheric turbulence. The study introduces a novel link-switching design that adapts to different weather conditions, such as fog and rain, effectively maintaining high-speed connections. This system improves upon traditional FSO systems by diversifying the FSO link, thereby reducing the impact of cloud blockage. Consequently, [33] highlight the importance of diversity techniques such as Signal Space Diversity (SSD) in improving system performance under fading conditions. Their analysis of distributed RIS-assisted dual-hop mixed RF-FSO systems shows that the combination of SSD and IRS can enhance spectral efficiency and diversity order, particularly when dealing with atmospheric turbulence modelled by Gamma-Gamma and Nakagami-m fading distributions. Similarly [85] provides a detailed performance analysis of hybrid FSO/RF systems under adverse climatic conditions, confirming that the deployment of IRS significantly reduces the outage

probability and ASER. The Monte Carlo simulations conducted in these studies consistently validate the theoretical models, proving that hybrid techniques are key to maintaining communication reliability in a complex environment.

6. Discussion and Conclusion

The integration of Reflection Intelligent Surfaces (RIS) into Free-Space Optical (FSO) systems presents a significant advancement in mitigating environmental challenges, particularly those caused by atmospheric turbulence, pointing errors, and misalignments. RIS technology has proven effective in enhancing performance metrics such as Average Symbol Error Rate (ASER) and outage probability under turbulent conditions, utilizing advanced models to optimize system resilience, even in harsh environmental conditions. One key area where RIS adds value is through the precise placement and configuration of RIS to counter pointing errors and system jitter. Optimizing RIS placement significantly improves system performance by maximizing beam alignment and minimizing signal distortions caused by environmental factors.

Additionally, RIS-sharing protocols have been proposed to address non-uniformity and misalignment issues in multi-link FSO systems, which reduces the Bit Error Rate (BER) and enhances overall system reliability. Despite these advancements, atmospheric turbulence and environmental conditions remain a critical challenge for FSO systems. RIS has demonstrated the ability to maintain system performance even under adverse weather conditions by employing strategies such as phase-shift optimization and multihop relaying. These methods enhance system performance and ensure reliable communication across longer distances and varying weather conditions. However, while these strategies significantly improve system reliability, they require advanced computational resources and precise system design, making large-scale deployment a complex task. Environmental factors like atmospheric turbulence, fog, and pointing errors are crucial considerations. By controlling the transmitter beam waist radius and minimizing pointing error displacement, it is possible to reduce ASER in RIS-assisted FSO systems. Atmospheric turbulence can severely impact data transmission, particularly under non-optimal environmental conditions.

However, FSO communication still outperforms traditional RF communication under similar conditions, suggesting that with proper optimizations, RIS-assisted FSO systems offer a superior alternative for weather-resilient communication. Several advanced methodologies, including diversity combining techniques like Maximal Ratio Combining (MRC) and cognitive RF-FSO strategies, show promise in overcoming environmental challenges. Hybrid FSO/RF systems that incorporate RIS technology significantly improve system energy efficiency and reliability, particularly in dense urban environments and challenging atmospheric conditions.

In conclusion, the integration of Reflection Intelligent Surfaces (RIS) into Free-Space Optical (FSO) systems offers significant advantages in enhancing system performance, particularly under challenging atmospheric conditions. RIS technology not only improves key metrics such as Bit Error Rate (BER), Signal-to-Noise Ratio (SNR), attenuation, and channel capacity but also increases energy efficiency and extends communication range. Additionally, RIS enhances link reliability and reduces latency, making it essential for maintaining robust communication links. The combination of RIS with hybrid FSO/RF systems further addresses the complexities posed by environmental factors, enabling adaptive network designs that ensure consistent, high-speed communication even in adverse weather. These systems also benefit from enhanced spectral efficiency and reduced outage probability. As ongoing research continues to refine these technologies, RIS emerges as a crucial innovation, providing substantial benefits in reliability,

efficiency, and overall system resilience for FSO communication networks.

Acknowledgement

References

[1] Yamane, Naoki, Yuki Inoue, Takuto Arai, Kenichi Kawamura, and Masayuki Ariyoshi. "Low Latency Redundant Network Architecture for Enhancing 5G Mobile Communication Quality." In *International Conference on Information Networking*, 88–92. The University of Tokyo, Graduate School of Information Science and Technology, Japan: IEEE Computer Society, 2025. https://doi.org/10.1109/ICOIN63865.2025.10993150.

[2] Mohd Razali, Syazwani, Razali Ngah, and Samir A. Al-Gailani. "Trends and Collaborative Networks in Reflective Intelligent Surface (RIS)-Enhanced Free Space Optics (FSO): A Bibliometric Analysis." *Elektrika: Journal of Electrical Engineering* 23, no. 3 (December 2024): 121–30. https://doi.org/10.11113/elektrika.v23n3.640.

[3] Cao, Yang, Chen Bao, Xiaofeng Peng, and Wei Xing. "Performance Analysis of RIS-Assisted FSO-RF Hybrid Systems Under Co-Channel Interference." *Guangxue Xuebao/Acta Optica Sinica* 44, no. 21 (2024). https://doi.org/10.3788/AOS230876.

[4] Suman, Bhanu, Vivek Kumar, and Abhishek Kumar. "Free Space Optical Communication for Tactical Environment: Potential Applications, Challenges and Mitigation Techniques." In *2024 International Conference on Computer, Electronics, Electrical Engineering and Their Applications (IC2E3 2024)*. Defence Electronics Applications Laboratory, Dehradun, India: Institute of Electrical and Electronics Engineers Inc., 2024. https://doi.org/10.1109/IC2E362166.2024.10827589.

[5] Mali, Sonali, Jayarajan Ratnam, Fawad A. Ali, and Pravas K. Sahoo. "A Review on Free Space Optical Communication Links: 5G Applications." *Journal of Optical Communications* 46, no. 4 (2025): 893–907. https://doi.org/10.1515/joc-2024-0109.

[6] Wang, Haobo, Jiaqi Li, Liang Zhang, and Wei Feng. "Navigating the Dual-Use Nature and Security Implications of Reconfigurable Intelligent Surfaces in Next-Generation Wireless Systems." *IEEE Communications Surveys & Tutorials* 28 (2026): 3346–87. https://doi.org/10.1109/COMST.2025.3621610.

[7] Sivaprasad, Ramya. "Reconfigurable Intelligent Surface for MmWaves and Multi-Antenna Systems: Design Challenges and Applications." In *Applications and Challenges of Reconfigurable Intelligent Surfaces in 6G*, 255–86. Sri Sairam Engineering College, India: IGI Global, 2025. https://doi.org/10.4018/979-8-3693-8099-4.ch011.

[8] Jamali, Vahid, Hossein Ajam, Mohammad Najafi, Bernhard Schmauss, Robert Schober, and H. Vincent Poor. "Intelligent Reflecting Surface Assisted Free-Space Optical Communications." *IEEE Communications Magazine* 59, no. 10 (2021): 57–63. https://doi.org/10.1109/MCOM.001.2100406.

[9] Shakir, Wael M. R., and Jawad Charafeddine. "Empowering MIMO-FSO Systems: RIS Technology for Enhanced Performance in Challenging Conditions." *IEEE Open Journal of the Communications Society* 6 (2025): 2616–41. https://doi.org/10.1109/OJCOMS.2025.3553813.

[10] Ndjiongue, Arsene R., Octavia A. Dobre, and Hyundong Shin. "On-Demand RIS-Assisted Free Space Optical Access System for 6G Networks." *IEEE Transactions on Vehicular Technology* 74, no. 6 (June 2025): 9059–70. https://doi.org/10.1109/TVT.2025.3532988.

[11] Chehimi, Mahmoud, Ramy T. El-Ganainy, Walid Gomaa, and Mohamed-Slim Alouini. "Reconfigurable Intelligent Surface (RIS)-Assisted Entanglement Distribution in FSO Quantum Networks." *IEEE Transactions on Wireless Communications* 24, no. 4 (April 2025): 3132–48. https://doi.org/10.1109/TWC.2025.3528103.

[12] Wang, Jiayuan, Dawei Gao, Jialong Li, Liang Huang, Hao Ding, and Shidong Zhou. "Analysis and Mitigating Methods for Jamming in the Optical Reconfigurable Intelligent Surfaces-Assisted Dual-Hop FSO Communication Systems." *Electronics* 13, no. 9 (April 2024):

1730. https://doi.org/10.3390/electronics13091730.

[13] Ata, Yasin, Anna Maria Vegni, and Mohamed-Slim Alouini. "RIS-Embedded UAVs Communications for Multi-Hop Fully-FSO Backhaul Links in 6G Networks." *IEEE Transactions on Vehicular Technology* 73, no. 10 (October 2024): 14143–58. https://doi.org/10.1109/TVT.2024.3414850.

[14] Vishwakarma, Neha, Swaminathan R., Panagiotis D. Diamantoulakis, and George K. Karagiannidis. "Cascaded FSO Systems With Optical Reflecting Surfaces." *IEEE Internet of Things Journal* 11, no. 23 (December 2024): 38631–44. https://doi.org/10.1109/JIOT.2024.3455577.

[15] Tarhouni, Fadil, Rui Wang, and Mohamed-Slim Alouini. "Free Space Optical Mesh Networks: A Survey." *IEEE Open Journal of the Communications Society* 6 (2025): 642–55. https://doi.org/10.1109/OJCOMS.2025.3525468.

[16] Huu Ai, Dang, Dang Tho Dang, Cong Dat Vuong, Van Loi Nguyen, and Kim Ty Luong. "Average Symbol Error Rate Analysis of Reconfigurable Intelligent Surfaces Based Free-Space Optical Link Over Weibull Distribution Channels." *International Journal of Electrical and Computer Engineering* 14, no. 1 (February 2024): 443. https://doi.org/10.11591/ijece.v14i1.pp443-450.

[17] Razali, Syazwani Mohd, Razali Ngah, Samir A. Al Gailani, and Yuwono Rahayu. "A Review of Free Space Optical (FSO) Communication Systems Enhanced by Reflective Intelligent Surfaces (RIS) Under Clear Weather Conditions Utilizing Geometric Principles." In *2024 IEEE Asia-Pacific Conference on Applied Electromagnetics (APACE)*, 219–22. IEEE, December 2024. https://doi.org/10.1109/APACE62360.2024.10876884.

[18] Tang, Siyuan, Xian-Ping Zhang, Jian Song, and Yi Dong. "Optimal Transceiver Design for RIS-Assisted FSO Communication Systems." In *2024 Asia Communications and Photonics Conference (ACP) and International Conference on Information Photonics and Optical Communications (IPOC)*, 1–3. IEEE, November 2024. https://doi.org/10.1109/ACP/IPOC63121.2024.10809974.

[19] Natiq, Balqees, and Liqaa Abdulameer. "A Systematic Review of Intelligent Reflecting Surface Aided Non-Orthogonal Multiple Access Beamforming-Based Free Space Optical Communication Systems." *Al-Qadisiyah Journal for Engineering Sciences* 18, no. 2 (June 2025): 155–62. https://doi.org/10.30772/qjes.2024.151005.1272.

[20] Uniyal, Shubham, Neha Vishwakarma, Divyang Singh, and Ramavath Swaminathan. "Reconfigurable Intelligent Surfaces-Aided Mixed THz/FSO Communication System." In *2024 National Conference on Communications (NCC)*, 1–6. IEEE, February 2024. https://doi.org/10.1109/NCC60321.2024.10485790.

[21] Rakib, Md Asraful, Md Ibrahim, Abu S. M. Badrudduza, Imran Shafique Ansari, M. Shamsul Uz Zaman, and Heejung Yu. "RIS-Aided Free-Space Optics Communications in A2G Networks over Inverted Gamma–Gamma Turbulent Channels." *ICT Express* 11, no. 1 (February 2025): 66–73. https://doi.org/10.1016/j.icte.2024.09.016.

[22] Kumar, Rahul, Ravi Singh, Vinay Kumar, and Rajeev Tripathi. "Average Symbol Error Probability of RIS-Assisted Mixed RF-FSO Communication System for Uplink Network." In *2025 Third International Conference on Microwave, Antenna and Communication (MAC)*, 1–4. IEEE, June 2025. https://doi.org/10.1109/MAC64480.2025.11140588.

[23] Elfikky, Abed, Ahmed I. Saleh, Moustafa H. Aly, and Mohy E. Abou-Elsoud. "Underwater Visible Light Communication: Recent Advancements and Channel Modeling." *Optical and Quantum Electronics* 56, no. 9 (2024). https://doi.org/10.1007/s11082-024-07426-z.

[24] Alimi, Isiaka A., and Paulo P. Monteiro. "RF/FSO and THz/FSO Relaying Systems." In *Handbook of Radio and Optical Networks Convergence*. Springer, 2024. https://doi.org/10.1007/978-981-33-4999-5_60-1.

[25] Abd El-Mottaleb, Samia A., Mehtab Singh, Ahmad Atieh, and Moustafa H. Aly. "High Data Rate Underwater Optical Wireless Communication Systems with ICSM Codes Within Green Spectrum." *Optical and Quantum Electronics* 57, no. 5 (2025). https://doi.org/10.1007/s11082-025-08065-8.

[26] Wang, Di, Menglin Wu, Zhongxiang Wei, Keping Yu, Le Min, and Shahid Mumtaz. "Uplink Secrecy Performance of RIS-Based RF/FSO Three-Dimension Heterogeneous Networks." *IEEE Transactions on Wireless Communications* 23, no. 3 (March 2024): 1798–1809. https://doi.org/10.1109/TWC.2023.3292073.

[27] Vishwakarma, Neha, Ramavath Swaminathan, R. Premanand, Shree Sharma, and A. S. Madhukumar. "RIS-Assisted Hybrid FSO/THz System With Diversity Combining Schemes: A Performance Analysis." *IEEE Internet of Things Journal* 11, no. 17 (September 2024): 28605–

22. https://doi.org/10.1109/JIOT.2024.3405973.

[28]   Uniyal, Shubham, Neha Vishwakarma, R. Swaminathan, and A. S. Madhukumar. "Intelligent-Reflecting-Surfaces-Assisted Hybrid FSO/RF Communication with Diversity Combining: A Performance Analysis." *Applied Optics* 62, no. 35 (December 2023): 9399. https://doi.org/10.1364/AO.502196.

[29]   Uniyal, Shubham, Neha Vishwakarma, and R. Swaminathan. "Multihop IRS-Assisted Free Space Optics Communication with DF Relaying: A Performance Analysis." *Applied Optics* 62, no. 27 (2023): 7284–94. https://doi.org/10.1364/ao.487194.

[30]   Elsayed, Ehab E., Mohamed A. Yakout, and Ahmed S. Samra. "Atmospheric Turbulence-Resilient Hybrid MIMO RF/FSO Communication Systems: Adaptive N-SM and OAM-OMI Assisted M-ary SPPM Modulation with Advanced Diversity Multiplexing for Next-Generation Wireless Networks." *Journal of Optical Communications*, June 2025. https://doi.org/10.1515/joc-2025-0210.

[31]   Ishida, Takuya, Chinthaka Ben Naila, Hiraku Okada, and Masao Katayama. "Performance Analysis of IRS-Assisted Multi-Link FSO System Under Pointing Errors." *IEEE Photonics Journal* 16, no. 4 (August 2024): 1–10. https://doi.org/10.1109/JPHOT.2024.3416201.

[32]   Zhao, Kailei, Jun Li, Kang An, and Zan Li. "RIS-Aided Communication Network Deployment Strategy Based on BP Model: From Single-Hop to Multi-Hop." *IEEE Transactions on Green Communications and Networking* 10 (2026): 397–411. https://doi.org/10.1109/TGCN.2025.3584069.

[33]   Wang, Jiayuan, Dawei Gao, Hao Ding, Jun Dong, Xian Zhang, and Jialong Li. "Performance Analysis of IRS-Assisted Multi-Link FSO System Under UAV-Enabled Jamming." In *ICC 2025 - IEEE International Conference on Communications*, 3125–31. IEEE, June 2025. https://doi.org/10.1109/ICC52391.2025.11161904.

[34]   Chen, Jianxin, Kang An, Xiaohu You, and Chau Yuen. "Hybrid Beamforming for RIS-Assisted Multiuser Fluid Antenna Systems." *IEEE Transactions on Wireless Communications* 25 (2026): 2718–32. https://doi.org/10.1109/TWC.2025.3598493.

[35]   Zhou, Fan, Zan Li, Derrick Wing Kwan Ng, and Octavia A. Dobre. "Performance Evaluations for RIS-Aided Satellite Aerial Terrestrial Integrated Networks With Link Selection Scheme and Practical Limitations." *IEEE Transactions on Network and Service Management* 22, no. 4 (August 2025): 3179–90. https://doi.org/10.1109/TNSM.2024.3476146.

[36]   Kitchenham, Barbara. "Guidelines for Performing Systematic Literature Reviews in Software Engineering." Technical report, Ver. 2.3 EBSE Technical Report. EBSE, 2007.

[37]   Abouzahra, Abdelhadi, Anas Sabraoui, and Karim Afdel. "Model Composition in Model Driven Engineering: A Systematic Literature Review." *Information and Software Technology* 125, no. May (2020): 106316. https://doi.org/10.1016/j.infsof.2020.106316.

[38]   Dabiri, Mohammad T., Mazen Hasna, and Khalid A. Qaraqe. "From Idealized Optical IRS Models to Realistic Lens-Based Architectures." *IEEE Wireless Communications Letters* 15 (2026): 166–70. https://doi.org/10.1109/LWC.2025.3620255.

[39]   Rahman, Tanvir U., Muhammad A. Khalid, Syed M. Zafi, and Shahid A. Khan. "Fiber-Array Beamforming and Modulation Scheme with Hybrid Switching Techniques for U2G-Free Space Optical Communication." *Optics and Laser Technology* 198 (2026). https://doi.org/10.1016/j.optlastec.2026.114787.

[40]   Zhang, Qi, Dan-Wen Yue, Shuai-Nan Jin, Xiang-Yang Xu, and Mei Wang. "Performance Analysis of Multi-RIS-Assisted UWOC Systems: Full Receiving Scheme and Selective Receiving Scheme." *IEEE Photonics Journal* 18, no. 1 (2026). https://doi.org/10.1109/JPHOT.2025.3647059.

[41]   Salam, Rizwan, and Vivek Ashok Bohara. "LC-OSTAR-IRS: Tunable Liquid Crystal Surfaces for High-Performance UWOC." *IEEE Wireless Communications Letters* 15 (2026): 1305–9. https://doi.org/10.1109/LWC.2026.3651802.

[42]   Ajam, Hossein, Mohammad Najafi, Vahid Jamali, and Robert Schober. "Optical IRSs: Power Scaling Law, Optimal Deployment, and Comparison with Relays." *IEEE Transactions on Communications* 72, no. 2 (2024): 954–70. https://doi.org/10.1109/TCOMM.2023.3327464.

[43]   Ata, Yasin, Fathi M. Al-Sallami, Mustafa C. Gökçe, Anna Maria Vegni, Sujan Rajbhandari, and Yahya Baykal. "Optical Wireless Communication in Atmosphere and Underwater: Statistical Models, Improvement Techniques, and Recent Applications." *IEEE Communications Surveys & Tutorials* 28 (2026): 4248–84. https://doi.org/10.1109/COMST.2025.3649735.

[44]   Vishwakarma, Neha, R. Premanand, R. Swaminathan, and A. S. Madhukumar. "RIS-Assisted MIMO THz

Communication Systems With Spatial Modulation: A Performance Analysis." *IEEE Transactions on Communications* 74 (2026): 2001–15. https://doi.org/10.1109/TCOMM.2025.3642729.

[45] Guo, Xiaoyong, Ying Lin, Dongming Pang, Xiang Li, Yang Song, and Kai Dong. "Beam-Deviation Compensation of FSM via Beam-Tracing Modeling in Dynamic Optomechanical Systems." *IEEE Photonics Technology Letters* 38, no. 6 (2026): 430–33. https://doi.org/10.1109/LPT.2025.3642279.

[46] Ajam, Hossein, Andreas Rittler, Vahid Jamali, Vasilis K. Papanikolaou, Bernhard Schmauss, and Robert Schober. "Modeling and Mitigation of Intersymbol Interference in High Rate IRS-Assisted FSO Links." *IEEE Transactions on Communications* 74 (2026): 1543–59. https://doi.org/10.1109/TCOMM.2025.3636084.

[47] Shang, Shijie, Emna Zedini, Abla Kammoun, and Mohamed-Slim Alouini. "Optical Intelligent Reflecting Surfaces Empowering Non-Terrestrial Communications." *IEEE Transactions on Wireless Communications* 25 (2026): 7083–99. https://doi.org/10.1109/TWC.2025.3628865.

[48] Kumar, Rajeev, Manoj K. Shukla, Vinay Kumar, and Rajeev Tripathi. "UAV-Enabled SAGIN: Investigating Multi-RIS Systems for Mixed FSO-RF Communication." *IEEE Transactions on Aerospace and Electronic Systems* 62 (2026): 1107–18. https://doi.org/10.1109/TAES.2025.3627512.

[49] Chen, Chen, Kexin Li, Junhao Ji, and Haifeng Zhao. "A Heterogeneous RIS-Assisted All-Optical Ocean-Air Integrated Network: Channel Modelling and Performance Analysis." *Physical Communication* 73 (2025). https://doi.org/10.1016/j.phycom.2025.102856.

[50] Xie, Jie, Haibo Zhou, Quansheng Guan, and Xuemin Shen. "Covert Communications for Dual-Hop FSO–RF Systems with NOMA." *Applied Optics* 64, no. 31 (2025): 9276–84. https://doi.org/10.1364/AO.568723.

[51] Raamesh, L., S. Anitha, S. Radhika, and A. Chandra Sekar. "A Quantum-Crossover Gravitational Search Algorithm for Energy-Efficient Power Allocation in Serial Relaying Underwater Wireless Optical Communication Systems." *International Journal of Communication Systems* 38, no. 13 (2025). https://doi.org/10.1002/dac.70169.

[52] Khatiwoda, Niraj R., Binod R. Dawadi, and Sajan R. Joshi. "Joint Placement Optimization and Sum Rate Maximization of RIS-Assisted UAV with LEO-Terrestrial Dual Wireless Backhaul." *Telecom* 6, no. 3 (2025). https://doi.org/10.3390/telecom6030061.

[53] Shi, Shuai, Jian Wang, Xiaoke Gao, and Lin Zhang. "Misalignment Tolerance Enhancement of Vector Beams in a Free-Space Optical Communication Link." *Optics Letters* 50, no. 2 (2025): 269–72. https://doi.org/10.1364/OL.542985.

[54] Li, Anhu, Jianfeng Ma, Xin Zhao, and Yun Liu. "Advances in Rotating Risley Prisms for Space-Optics Applications." *Optical Engineering* 64, no. 8 (2025). https://doi.org/10.1117/1.OE.64.8.080901.

[55] AbdElKader, Ahmed G., Adel Allam, Koichi Kato, and Hossam M. H. Shalaby. "Performance Analysis of a UAV-Integrated RIS-Aided MRR-FSO System Utilizing Wavelength and Time Diversity Techniques." *Photonic Network Communications* 50, no. 1 (2025). https://doi.org/10.1007/s11107-025-01031-0.

[56] Gupta, Ankur, D. Divya, Nitesh Gupta, and Hemani Kaushal. "On the Performance of a UAV-Based Malaga-Distributed FSO/FSO Communication System with NOMA." *Vehicular Communications* 54 (2025). https://doi.org/10.1016/j.vehcom.2025.100930.

[57] Zhang, Jie, Pengfei Wang, Hao Wu, and Lei Liu. "Constellation Symbol OAM Encoding for an Atmospheric Turbulence-Resistant Optical Transmission Method Based on Trellis-Coded Modulation." *Applied Optics* 64, no. 21 (2025): 6143–49. https://doi.org/10.1364/AO.568568.

[58] Liu, Xiaoyu, Xiaofeng Li, Zhongyang Deng, and Haifeng Sun. "Optimization and Verification of Acquisition Time Method Based on a Data-Driven Model for Laser Inter-Satellite Links." *Electronics* 14, no. 14 (2025). https://doi.org/10.3390/electronics14142854.

[59] Kumar Ghosh, Manoj, and Mostafa Zaman Chowdhury. "Enhancing Underwater Acoustic Communication Networks with RIS: Precise Performance Analysis over κ–μ Shadowed Fading Distribution." *Results in Engineering* 26 (2025). https://doi.org/10.1016/j.rineng.2025.105446.

[60] Gupta, Ankur, D. Divya, Nitesh Gupta, and Hemani Kaushal. "Investigation of Outage Performance in NOMA-Based Dual-Hop FSO Communication." *Wireless Personal Communications* 141, no. 1 (2025): 169–90. https://doi.org/10.1007/s11277-025-11775-7.

[61] Hearne, Shane, John Horgan, Noureddine Boujnah, and Donagh Kilbane. "Wavelength Selection for Satellite Quantum Key Distribution." *Applied Sciences* 15, no. 3

(2025). https://doi.org/10.3390/app15031308.

[62] Duong, Dang H., Hoang H. Duc, Kim T. Luong, and Nguyen D. Ngoc. "Effects of Atmospheric Turbulence and Reconfigurable Intelligent Surfaces on Near Terrestrial Optical Link for Internet of Things." *Telkomnika (Telecommunication Computing Electronics and Control)* 23, no. 1 (2025): 66–72. https://doi.org/10.12928/TELKOMNIKA.v23i1.25521.

[63] Qian, Lipeng, Fan Wu, Di Wang, Nianfei Huang, and Zhengyuan Xu. "Optical RIS-Aided Covert Visible Light Communications." *IEEE Transactions on Vehicular Technology* 74, no. 7 (2025): 11518–23. https://doi.org/10.1109/TVT.2025.3545851.

[64] Dabiri, Mohammad T., Mazen Hasna, and Khalid Qaraqe. "From Idealized Optical IRS Models to Realistic Lens-Based Architectures." *IEEE Wireless Communications Letters* 14, no. 5 (2025): 1264–68. https://doi.org/10.1109/LWC.2025.3620255.

[65] Zhang, Xiaoyu, Rui Wang, Jianping Yao, and Kun Qiu. "A Weather-Dependent UAV Relay-Assisted Hybrid FSO/RF Airborne Communication System." *Optics Communications* 554 (2024). https://doi.org/10.1016/j.optcom.2023.130196.

[66] Ata, Yasin, Xiaowen Yi, Yong Li, Xiaofeng Tao, and Anna Maria Vegni. "A Unified Channel Model for IRS-Aided Underwater OWC With Combined Attenuation Losses." *IEEE Journal on Selected Areas in Communications* 43, no. 5 (2025): 1552–67. https://doi.org/10.1109/JSAC.2025.3543523.

[67] Redasni, Akhil, Neha Vishwakarma, and Ramavath Swaminathan. "Adaptive-Combining-Based RIS-Aided Hybrid FSO/RF System: A Performance Analysis." In *Proceedings of the National Conference on Communications (NCC 2025)*. IEEE, 2025. https://doi.org/10.1109/NCC63735.2025.10982729.

[68] Al-Tamimi, Nedhal, Aisha F. Al Kahlout, Adel M. Qahtan, and Anwar A. M. Alqanoo. "Innovative Closed Cavity Façades (CCF) with Inner Shading and Advanced Coatings for Enhancing Thermal Performance in the Tropics." *Buildings* 14, no. 3 (February 2024): 603. https://doi.org/10.3390/buildings14030603.

[69] Shakir, Wael M. R., and Jawad Charafeddine. "Empowering MIMO-FSO Systems: RIS Technology for Enhanced Performance in Challenging Conditions." *IEEE Open Journal of the Communications Society* 6 (2025): 2616–41. https://doi.org/10.1109/ojcoms.2025.3553813.

[70] Ai, Dang Huu, Dang Tho Dang, Nguyen Van Quang, and Van Loi Nguyen. "Analysis on the Performance of Reconfigurable Intelligent Surface-Aided Free-Space Optical Link Under Atmospheric Turbulence and Pointing Errors." *International Journal of Electrical and Computer Engineering* 13, no. 4 (2023): 4204. https://doi.org/10.11591/ijece.v13i4.pp4204-4211.

[71] Hussein, Mustafa M., and M. A. Askar. "Enhance Data and Power Transmission in Free-Space Optical Systems Under Environmental Circumstances." *International Journal of Intelligent Systems and Applications in Engineering* 11, no. 5s (2023): 67–77. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85158140794&partnerID=40&md5=a73ebd6f397514d921c0fe3c43e79aa8.

[72] Khayatian, Hamidreza, Mohammadreza Malekmohammadi, Amin Ghods, and Ahmadreza Montazerolghaem. "Trajectory and Phase Shift Optimization for RIS-Equipped UAV in FSO Communications with Atmospheric and Pointing Error Loss." *Optical and Quantum Electronics* 10, no. 1 (March 2023): 1–15. https://doi.org/10.3390/electronics12204275.

[73] Le, Hoang D., and Anh T. Pham. "Link-Layer Retransmission-Based Error-Control Protocols in FSO Communications: A Survey." *IEEE Communications Surveys & Tutorials* 24, no. 3 (2022): 1602–33. https://doi.org/10.1109/COMST.2022.3175509.

[74] Wang, Jiayuan, Dawei Gao, Jialong Li, Liang Huang, Hao Ding, and Shidong Zhou. "Analysis and Mitigating Methods for Jamming in the Optical Reconfigurable Intelligent Surfaces-Assisted Dual-Hop FSO Communication Systems." *Electronics* 13, no. 9 (2024). https://doi.org/10.3390/electronics13091730.

[75] Roa, César A., Yunus C. Gültekin, Kuangda Wu, Cornelis W. Korevaar, and Alex Alvarado. "On Error Rate Approximations for FSO Systems With Weak Turbulence and Pointing Errors." *IEEE Journal of Selected Topics in Quantum Electronics* 32, no. 1: Advances in Free Space Laser (January 2026): 1–15. https://doi.org/10.1109/JSTQE.2025.3590410.

[76] Rajput, Sagar J., Mehul B. Patel, and Sandip H. Patel. "Analysis of 25 Gbps 4-QAM-Modulated Coherent OFDM-FSO Link Employing LDPC Channel Coding Across Diverse Atmospheric Scenarios." *Journal of Optical Communications*, September 2025. https://doi.org/10.1515/joc-2025-0198.

[77] Challapalli, Raghavaiah, and Poongodi Chitra. "Investigating MIMO Technology in Free Space Optical Communication Systems for Evaluating Performance Across Various Environment Parameters." *Results*

in Engineering 25 (March 2025): 103617. https://doi.org/10.1016/j.rineng.2024.103617.

[78] Belgaonkar, Veerendra V., R. Sundaraguru, and C. Poongothai. "Enhancing Free Space Optical System Performance through Fog and Atmospheric Turbulence Using Power Optimization." *Engineering, Technology and Applied Science Research* 15, no. 1 (February 2025): 19390–95. https://doi.org/10.48084/etasr.8487.

[79] Nafees, Muhammad, Mahdi Baniasadi, James R. Hopgood, Majid Safari, and John S. Thompson. "Integrated Sensing and Communication for UAV Trajectory Optimization in Mixed FSO-RF Networks in Dynamic Weather Conditions." In *2025 IEEE Wireless Communications and Networking Conference (WCNC)*, 1–6. IEEE, March 2025. https://doi.org/10.1109/WCNC61545.2025.10978163.

[80] Agheli, Parisa, Hamzeh Beyranvand, and Mohammad Javad Emadi. "High-Speed Trains Access Connectivity Through RIS-Assisted FSO Communications." *Journal of Lightwave Technology* 40, no. 21 (2022): 7084–94. https://doi.org/10.1109/JLT.2022.3199608.

[81] Le, Hoang D., Canh T. Nguyen, Thu K. Nguyen, and Anh T. Pham. "Hybrid FSO/Sub-THz-Based Vertical Networks for Internet of Vehicles." *IEEE Transactions on Aerospace and Electronic Systems* 60, no. 2 (2024): 1865–81. https://doi.org/10.1109/TAES.2023.3342789.

[82] Mondal, Soumitra, Keshav Singh, Chun-Pang Lit, and Shankar Prakriya. "Mixed FSO/IRS-Aided NOMA Network with Heterogeneous Channels." In *2025 IEEE Wireless Communications and Networking Conference (WCNC)*, 1–6. IEEE, March 2025. https://doi.org/10.1109/WCNC61545.2025.10978454.

[83] Nguyen, Thanh V., Hoang D. Le, and Anh T. Pham. "On the Design of RIS-UAV Relay-Assisted Hybrid FSO/RF Satellite-Aerial-Ground Integrated Network." *IEEE Transactions on Aerospace and Electronic Systems* 59, no. 2 (2023): 757–71. https://doi.org/10.1109/TAES.2022.3189334.

[84] Uniyal, Shubham, Neha Vishwakarma, Divyang Singh, and Ramavath Swaminathan. "Reconfigurable Intelligent Surfaces-Aided Mixed THz/FSO Communication System." In *2024 National Conference on Communications (NCC)*. Indian Institute of Technology (IIT), Department of Electrical Engineering, Indore, India: Institute of Electrical and Electronics Engineers Inc., 2024. https://doi.org/10.1109/NCC60321.2024.10485790.

Background of selected study:

No	Authors	Title	Year	Journal	Scopus	WoS	IEEE
1	Dabiri, M.T.; Hasna, M.; Qaraqe, K.A. [38]	From Idealized Optical IRS Models to Realistic Lens-Based Architectures	2026	IEEE	✓		✓
2	Rahman, T.U.; Li, G.; Ali, F.; Khan, A.D.; Rehman, A.; Ouyang, Z.; Afsar, H.; Alshamrani, A.; Roslee, M. [39]	Fiber-array beamforming and modulation scheme with hybrid switching techniques for U2G-free space optical communication	2026	Elsevier	✓	✓	
3	Zhang, Q.; Yue, D-W.; Jin, S.-N.; Xu, X.-Y.; Wang, M. [40]	Performance Analysis of Multi-RIS-Assisted UWOC Systems: Full Receiving Scheme and Selective Receiving Scheme	2026	IEEE	✓		✓
4	Liu, Z.; Yang, F.; Song, J.; Han, Z. [32]	Optical Intelligent Reflecting Surface-Assisted Visible Light Covert Communication With NOMA: An Effective Covert Spectral Efficiency	2026	IEEE	✓		✓
5	Salam, R.; Ashok Bohara, V. [41]	LC-OSTAR-IRS: Tunable Liquid Crystal Surfaces for High-Performance UWOC	2026	IEEE	✓		✓
6	Ajam H., Najafi M., Jamali V., Schober R.[42]	Optical IRSs: Power Scaling Law, Optimal Deployment, and Comparison with Relays.	2026	IEEE	✓		✓
7	Ata, Y.; Al-Sallami, F.M.; Gökçe, M.C.; Vegni, A.M.; Rajbhandari, S.; Baykal, Y. [43]	Optical Wireless Communication in Atmosphere and Underwater: Statistical Models, Improvement Techniques, and Recent Applications	2026	IEEE	✓		✓
8	Vishwakarma, N.; Premanand, R.; Swaminathan, R.; Madhukumar, A.S. [44]	RIS-Assisted MIMO THz Communication Systems with Spatial Modulation: A Performance Analysis	2026	IEEE	✓		✓
9	Guo, X.; Lin, Y.; Pang, D.; Li, X.; Song, Y.; Dong, K. [45]	Beam-Deviation Compensation of FSM via Beam-Tracing Modeling in Dynamic Optomechanical Systems	2026	IEEE	✓		✓
10	Ajam, H.; Rittler, A.; Jamali, V.; Papanikolaou, V.K.; Schmauss, B.; Schober, R. [46]	Modeling and Mitigation of Intersymbol Interference in High-Rate IRS-Assisted FSO Links	2026	IEEE	✓		✓
11	Shang, S.; Zedini, E.; Kammoun, A.; Alouini, M.-S. [47].	Optical Intelligent Reflecting Surfaces Empowering Non-Terrestrial Communications	2026	IEEE	✓	✓	✓
12	Kumar, R.; Shukla, M.K.; Kumar, V.; Tripathi, R. [48].	UAV-Enabled SAGIN: Investigating Multi-RIS Systems for Mixed FSO-RF Communication	2026	IEEE	✓	✓	✓

No	Authors	Title	Year	Journal	Scopus	WoS	IEEE
13	Shang, S.; Zedini, E.; Kammoun, A.; Alouini, M.-S. [49]	A Novel Hybrid Optical and STAR IRS System for NTN Communications	2026	IEEE	✓		✓
14	Chen, C.; Li, K.; Ji, J.; Zhao, H. [50]	A heterogeneous RIS-assisted all-optical ocean-air integrated network: Channel modelling and performance analysis	2025	Elsevier	✓		✓
15	Wang, J.; Gao, D.; Zhang, X.; Ding, D. [33]	ABER and outage probability of FSO systems under UAV-assisted symbol-level jamming over turbulent channels with pointing errors	2025	Elsevier	✓		✓
16	Xie, J.; Zhang, J.; Li, J.; Ding, X.; Wang, S.; Xie, Y.; Pan, G. (Xie et al.,	Covert communications for dual-hop FSO–RF systems with NOMA	2025	Optica (OSA)	✓		
17	Li, H.; Pang, W.; Li, S.; Wang, P.; Li, H.; Hao, W.; Hui, X. [51]	Performance analysis of Dual-Client FSO communication system with UAV-Mounted STAR-RIS considering ES protocol over atmospheric IGGG distribution	2025	Elsevier	✓		✓
18	Kumar, A.; Dewangan, K.; Krishnan, P. (Kumar et al., 2025)	Channel capacity enhancement of RIS-assisted FSO communication system for high-speed trains access connectivity	2025	Elsevier	✓		✓
19	Raamesh, L.; Anitha, S.; Radhika, S.; Chandra Sekar, A. [52]	A Quantum-Crossover Gravitational Search Algorithm for Energy-Efficient Power Allocation in Serial Relaying Underwater Wireless Optical Communication Systems	2025	Wiley	✓		
20	Khatiwoda, N.R.; Dawadi, B.R.; Joshi, S.R. [53]	Phase-Shift Design and Channel Modelling for Focused Beams in IRS-Assisted FSO Systems. Joint Placement Optimization and Sum Rate Maximization of RIS-Assisted UAV with LEO-Terrestrial Dual	2025	MDPI	✓		
21	Zhang, H.-J.; Lin, P.; Wang, T.; Zhang, Z.-Q.; Zhao, B.-Q.; Jiao, W.-F.; Yu, X.-N. [54]	Performance of digital filtering and synchronization method for APD communication receiver	2025	KeAi	✓		
22	Li, A.; Ma, J.; Zhao, X.; Liu, Y. [55]	Advances in rotating Risley prisms for space-optics applications	2025	SPIE	✓		
23	AbdElKader, A.G.; Allam, A.; Kato, K.; Shalaby, H.M.H. [56]	Performance analysis of a UAV-integrated RIS-aided MRR-FSO system utilizing wavelength and time diversity techniques	2025	Springer	✓	✓	
24	Gupta, A.; Divya, D.; Gupta, N.; Kaushal, H. [57]	Analysis of Jamming Effects in IRS-Assisted UAV Dual-Hop FSO Communication Systems. On the performance of a UAV-based	2025	Elsevier	✓	✓	✓

No	Authors	Title	Year	Journal	Scopus	WoS	IEEE
25	Zhang, J.; Dong, X.; Xu, S.; Han, F.; Fang, J.; Wang, X.; Zhang, X.; Zhao, Q.; Ding, W.; Xia, Y.; Hu, Y. [58]	Constellation symbol OAM encoding for an atmospheric turbulence-resistant optical transmission method based on trellis-coded modulation	2025	Optica (OSA)	✓		
26	Liu, X.; Li, X.; Deng, Z.; Sun, H. [59]	Optimization and Verification of Acquisition Time Method Based on a Data-Driven Model for Laser	2025	MDPI	✓		
27	M. Kumar Ghosh and M. Z. Chowdhury [60]	Enhancing underwater acoustic communication networks with RIS: Precise performance analysis over κ-μ shadowed fading distribution	2025	Elsevier	✓		✓
28	Gupta, A.; Divya, D.; Gupta, N.; Kaushal, H. [61]	Investigation of Outage Performance in NOMA-based Dual-hop FSO Communication	2025	Springer	✓		
29	Hearne, S.; Horgan, J.; Boujnah, N.; Kilbane, D. [62]	Wavelength Selection for Satellite Quantum Key Distribution	2025	MDPI	✓		
30	Duong, D.H.; Duc, H.H.; Luong, K.T.; Ngoc, N.D. [63]	Effects of atmospheric turbulence and reconfigurable intelligent surfaces on near terrestrial optical link for internet of things	2025	Universitas Ahmad Dahlan	✓		
31	Natiq, B.R.; Abdulameer, L.F.[19]	Performance Analysis of Reconfigurable STAR-Passive-OIRS Aided NOMA Beamforming Based FSO Heterogeneous Networks for Beyond 5G	2025	Intelligent Network and Systems	✓		
32	Qian, L.; Wu, F.; Wang, D.; Huang, N.; Xu, Z. [64]	Optical RIS-Aided Covert Visible Light Communications	2025	IEEE	✓		✓
33	Dabiri, M.T.; Hasna, M. [65]	A Novel MRR-UAV-Based Relay with Optical Network Coding: A Comparative Study with Optical IRS and Conventional UAV Relaying	2025	IEEE	✓		✓
34	Zhang X., Zhao S., Wang Y., Wang X., Tian Q., Song X., Li X [66]	A weather-dependent UAV relay-assisted hybrid FSO/RF airborne communication system.	2024	Optics Communications	✓		
	Ata, Y.; Yi, X.; Li, Y.; Tao, X.; Vegni, A.M.[67]	A Unified Channel Model for IRS-Aided Underwater OWC With Combined Attenuation Losses	2025	IEEE	✓		✓