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Trends and Collaborative Networks in Reflective Intelligent Surface (RIS)-Enhanced Free Space Optics (FSO): A Bibliometric Analysis

Shahrizan Mohd Razali[1*], **Razali Ngah**[1] and **Samir A. Al-Gailani**[1]

[1]Wireless Communication Centre Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia

[*]Corresponding author: mohdrazali@graduate.utm.my

Abstract: This bibliometric analysis investigates research trends and collaborative networks in the emerging field of Reflective Intelligent Surface (RIS)-Enhanced Free Space Optics (FSO) to understand its growth and impact. With the rising complexity of modern wireless communication systems, RIS-enhanced FSO has gained attention for its potential to address challenges related to signal quality, energy efficiency, and resilience in diverse environments. Despite this potential, gaps remain in understanding collaboration patterns, influential contributions, and key research themes. Using Scopus Analyzer and VOSviewer software, a dataset of 1,449 publications was analysed to identify major contributors, popular keywords, and global collaboration trends. The methodology involved mapping co-authorship networks and keyword co-occurrences, enabling a detailed examination of prominent research areas and key geographical hubs. The results show a steady increase in publication volume from 2017 onward, indicating heightened research interest, particularly between 2022 and 2023. Popular keywords such as "signal to noise ratio," "bit error rate," and "atmospheric turbulence" highlight the focus on enhancing communication reliability and mitigating environmental impacts on FSO systems. Key contributors and collaborations were identified, with notable influence from researchers and institutions across multiple countries, underscoring the field’s interdisciplinary and global nature. This study concludes that RIS-enhanced FSO research is primarily driven by engineering and computational disciplines, with increasing attention to practical applications. The expanding collaborative network reflects a collective effort to overcome technical challenges and optimize RIS applications for future communication needs, establishing RIS-enhanced FSO as a vital area for next-generation wireless innovation.

Keywords: RIS, FSO, trends, bibliometric

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1. INTRODUCTION

Reflective Intelligent Surfaces (RIS) have emerged as a transformative technology in the realm of Free Space Optics (FSO), offering promising solutions to the inherent challenges faced by traditional FSO systems [1], [2]. FSO systems are known for their high data rates, secure communication links, and cost efficiency, making them ideal for applications such as wireless front and backhauling in 5G and 6G networks [3], [4]. However, the necessity for a line-of-sight connection between the transmitter and receiver has been a significant limiting factor in their widespread deployment[5]. The integration of RIS into FSO systems presents a novel approach to mitigate this limitation by enabling the redirection of optical signals, thereby enhancing the flexibility and robustness of FSO links [6]–[8]. The concept of RIS involves the use of reconfigurable surfaces composed of numerous low-cost, passive reflecting elements that can intelligently adjust the phase of incident light to steer it in desired directions [9]. This capability is particularly beneficial in overcoming obstacles such as atmospheric turbulence, pointing errors, and signal blockages, which are common in urban environments and smart-city applications [10], [11]. By employing RIS, FSO systems can maintain reliable connectivity even in the presence of physical obstructions and adverse weather conditions, thus significantly improving their performance and coverage area [12], [13] Recent studies have demonstrated the potential of RIS-enhanced FSO systems in various scenarios. For instance, the use of RIS has been shown to improve the link reliability and spectral efficiency of FSO systems, making them more resilient to environmental factors [10], [13]. Additionally, RIS can be utilized in dual-hop communication setups, where it aids in bridging the gap between FSO and radio frequency (RF) links, thereby extending the reach and enhancing the overall system performance [14], [15]. These advancements highlight the versatility and effectiveness of RIS in addressing the challenges faced by traditional FSO systems [7], [16], [17].

Moreover, the integration of RIS into FSO systems is not only limited to enhancing communication links but also extends to applications such as high-speed train connectivity and secure communication [18], [19]. For example, RIS-assisted FSO systems have been proposed to provide broadband internet access for high-speed trains, offering significant improvements in data rates and coverage areas compared to conventional relay-assisted setups [20]. Additionally, the ability of RIS to direct light towards legitimate users while blocking eavesdroppers' reception underscores its potential in enhancing the security of optical communication links [17], [21]. The incorporation of Reflective Intelligent Surfaces into Free Space Optics represents a significant leap forward in optical communication technology[22]. By addressing the limitations of traditional FSO systems and offering enhanced performance, reliability, and security, RIS-enhanced FSO systems are poised to play a crucial role in the development of next-generation wireless communication networks [23].

To guide this bibliometric study, several key research questions were formulated to uncover insights into the development and collaboration patterns in the field of RIS-enhanced FSO systems. These questions include: What are the research trends in RIS-FSO? Who writes the most cited articles? What is the type of document by subject of research? Who are the top 10 authors based on citation? What is the map of co-authorship about research trends and collaborative networks? And what are the popular keywords related to this study? These questions aim to provide a comprehensive understanding of the field’s growth, the influential contributors, and the emerging themes that shape this area of research

2. LITERATURE REVIEW

Reflective Intelligent Surfaces (RIS) have emerged as a promising solution to enhance Free Space Optical (FSO) communication systems by mitigating challenges such as signal obstruction and atmospheric turbulence [24], [25]. Ndjiongue et al. (2021) [26] explored a power-amplifying RIS design to address the "double-fading" effect in near-terrestrial FSO systems. By using liquid crystal on silicon (LCoS) technology, they demonstrated that the RIS design could directly amplify light and reduce power loss, offering potential benefits in regions with harsh environmental conditions. However, challenges in practical implementation, such as high attenuation, highlight limitations that need further exploration [24], [26]. Ajam et al. (2024) [27] further examined the power scaling laws for FSO RIS and highlighted the need for optimal IRS placement to maximize efficiency in varying signal strength scenarios, though this study’s scope is limited by its reliance on idealized conditions. A key advantage of RIS in FSO systems is its ability to alleviate line of sight (LOS) dependency, as discussed by Ajam et al. (2024) and Kumar et al. (2022) [28], [29]. These studies explored how RIS can support FSO communication over longer distances with better reliability by enabling triple-hop RF-FSO connections, which reduce link disruptions caused by environmental obstacles. This finding is corroborated by Saxena and Chung (2023) [30], who analyzed dual-hop FSO systems in the presence of malicious jamming, demonstrating that RIS integration can improve system resilience against signal interference. Nonetheless, while multi-hop RIS designs enhance performance under controlled turbulence conditions, further research is needed to address real-world variabilities such as unpredictable weather patterns and pointing errors [28]–[30]

RIS-enhanced FSO systems have also shown promise in increasing link reliability under adverse conditions. Pang et al. (2023) [24] analysed an FSO system using multiple detectors and partially coherent beams (PCB) to mitigate atmospheric turbulence effects. Their results showed that aperture diversity techniques, like maximum ratio combining (MRC), substantially improved signal quality. Similarly, Ai et al. (2023) [31] investigated RIS-aided FSO systems with pointing error and atmospheric turbulence, concluding that RIS technology could significantly extend the link distance while maintaining performance. However, these approaches often require advanced configurations, such as multiple detectors or precise alignment, making practical deployment more complex and costly [24], [31]. A growing trend in RIS-aided FSO research is its application in hybrid RF-FSO systems, enabling seamless communication across various environments. For example, Alnwaimi and Boujemaa (2021) [32] proposed a dual-hop RIS-based RF-FSO system, achieving notable gains in signal strength and reliability. This hybrid approach allows FSO systems to benefit from RF’s resilience in obstructed areas while maintaining FSO’s high data rates in clear channels. Rahman et al. (2023) [33] took this further by analyzing secrecy performance in RIS-assisted mixed RF-FSO systems, highlighting RIS’s role in enhancing physical layer security. However, while these hybrid models show potential, practical challenges such as synchronization and signal quality across different channels remain largely unaddressed [32], [33].

Despite advances, current RIS-FSO research exhibits significant gaps, particularly in practical deployment and scalability [22], [23], [34]. For instance, Ai et al. (2023) [31] emphasized the limitations imposed by pointing errors, especially over longer distances, which disrupt the signal and increase symbol error rates. Pang et al. (2023) [24] similarly noted that building sway and other environmental factors can degrade system reliability, indicating a need for more robust configurations that can adapt dynamically to physical disturbances. Additionally, Ai et al. (2023) [31] pointed out that while RIS can improve link stability, it remains sensitive to high turbulence levels, which reduces system performance significantly. These limitations underscore the importance of developing adaptive techniques for real-time environmental fluctuations [24], [31]. RIS has proven beneficial in enhancing FSO systems, existing studies highlight the need for further research to address practical deployment challenges, especially in adverse environmental conditions. Future research should focus on optimizing RIS configurations to handle pointing errors, integrating adaptive technologies for real-time adjustments, and exploring scalable solutions for large-scale applications.

FSO systems enhanced with RIS present a transformative approach to overcoming the limitations posed by environmental factors in optical communication, particularly in tropical climates like Malaysia [35]. RIS technology leverages programmable surfaces composed of meta-materials to manipulate the reflection and direction of optical signals, mitigating issues such as atmospheric turbulence, signal obstruction, and the stringent LoS requirements of traditional FSO systems [27], [36]. By dynamically adjusting the phase and angle of reflected signals, RIS improves the Signal to Noise Ratio (SNR) and reduces Bit Error Rate BER, enabling reliable communication even in challenging conditions [24], [37]. Research has shown the effectiveness of RIS in dual-hop and hybrid RF-FSO systems, where it bridges signal interruptions caused by obstacles and weather variability [38], [39]. Advanced configurations, such as liquid crystal on silicon (LCoS) technology, further enhance RIS performance by directly amplifying signals and reducing power loss, demonstrating potential for practical deployment in regions with high humidity and rainfall [40]. Despite these advancements, challenges such as the precise placement of RIS, real-time optimization, and sensitivity to extreme weather conditions remain open areas for exploration. Addressing these gaps through robust simulations and adaptive algorithms will be key to unlocking the full potential of RIS-enhanced FSO systems for high-capacity, resilient communication infrastructures in Malaysia [41]–[43]. Recent studies emphasize machine learning (ML) algorithms to optimize RIS configurations for FSO systems in dynamic environments [44], [45]. ML models enhance real-time adaptability, reduce turbulence effects, and improve energy efficiency, addressing scalability and deployment challenges [46], [47]. These techniques mitigate heavy rainfall, humidity, and temperature impacts in tropical climates like Malaysia [48]–[52].

3. METHODOLOGY

Bibliometrics means the combination, managing and investigation of bibliographic information obtained from publications which are scientific in nature [53]–[55]. Along with general descriptive statistics, such as, publishing journals, publication year and main author classification [56]; it also comprises complex techniques, such as, document co-citation analysis. A successful literature review necessitates an iterative process involving the identification of appropriate keywords, literature search, and thorough analysis to build a comprehensive bibliography and yield dependable results [57]. Considering this, the study sought to focus on top-tier publications, as they offer valuable insights into the theoretical perspectives shaping the evolution of the research domain. To ensure data reliability, the study relied on the SCOPUS database for data collection [58]–[60]. Moreover, in order to ensure the inclusion of high-quality publications, only articles published in rigorously peer-reviewed academic journals were considered, with a deliberate exclusion of books and lecture notes [61]. Notably, Elsevier’s Scopus, known for its extensive coverage, facilitated the collection of publications spanning from 2020 to December 2023 for subsequent analysis.

3.1 Data Search Strategy

The tables below summarize the search parameters and selection criteria applied to identify relevant literature for this study. Table 1 outlines the search string used in Scopus, designed to retrieve studies focused on "Reflective Intelligent Surfaces" (RIS) and their FSO, or other quantitative aspects published between 2020 and 2025 in peer-reviewed journal articles in English. Table 2 details the inclusion and exclusion criteria for the literature selection. Only English-language journal articles published within the 2020-2025 timeframe were included, while literature types such as books, reviews, or non-English publications were excluded to ensure relevance and consistency across the selected resources.

Table 1. The search string

Scopus	TITLE-ABS-KEY ((fso OR "free space optic" OR "optic*") AND ("reflect* intelligent* surface*" OR "Intelligent* reflection* surface*" OR "reconfigure* intelligent* surface*" OR "reflect* Intelligence* Surface*" OR "Intelligence* reflect* surface*" OR "RSI" OR "IRS" OR "RIS")) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (PUBSTAGE , "final"))

Table 2. The selection criterion is searching

Criterion	Inclusion	Exclusion
Language	English	Non-English
Literature type	Journal (Article)	Book, Review

3.2 Data Analysis

VOSviewer, developed by Nees Jan van Eck and Ludo Waltman at Leiden University in the Netherlands, is a widely accessible bibliometric tool that helps researchers visualize and analyse scientific literature [62], [63]. Known for its capability to create network visualizations, cluster related items, and generate density maps, VOSviewer makes it easier to explore complex research data. Researchers can use it to analyse co-authorship, co-citation, and keyword co-occurrence networks, gaining a broader perspective on research trends and connections. With its interactive interface and frequent updates, VOSviewer supports the dynamic exploration of large datasets. The tool's range of features including metrics computation, customizable visualizations, and compatibility with different bibliometric sources adds significant value for scholars aiming to gain in-depth insights into intricate research areas. A distinctive feature of VOSviewer is its ability to turn detailed bibliometric datasets into visually interpretable maps and graphs. The software emphasizes network visualization, excelling in clustering related terms, examining keyword co-occurrence patterns, and producing density maps. Its user-friendly design caters to both new and experienced researchers, enabling efficient exploration of research landscapes. The software's continuous development keeps it at the cutting edge of bibliometric analysis, providing insights through metrics calculations and adaptable visualizations. This flexibility with various bibliometric data types, including co-authorship and citation networks, makes VOSviewer an essential tool for scholars looking to deepen their understanding of their fields. For this study, datasets in Plaintext format containing information such as publication year, title, author name, journal, citations, and keywords were obtained from the Scopus database, covering the years 2020 to December 2023. These datasets were analysed using VOSviewer version 1.6.19. By applying VOS clustering and mapping techniques, the software enabled the generation of maps that offer a clear visual representation of research data. Unlike Multidimensional Scaling (MDS), VOSViewer emphasizes positioning items in low-dimensional spaces, ensuring that the distance between items reflects their similarity and relatedness [63]. Although VOSViewer shares some similarities with MDS in this approach [64], it employs association strength (ASij) as a more suitable method for normalizing co-occurrence frequencies, which is calculated as follows [65]:

$$AS_{ij} = \frac{1/_4 c_{ij}}{w_i w_j} \qquad (1)$$

which is "proportional to the ratio between on the one hand the observed number of cooccurrences of i and j and on the other hand the expected number of co-occurrences of i and j under the assumption that co-occurrences of i and j are statistically independent" [63]. Hence, with help of this index, VOSviewer places items in the form of a map after reducing the weighted sum of the squared distances between all item pairs. According to Appio et al. (2016) [64], the LinLog/modularity normalization was implemented. Furthermore, by applying visualization techniques through VOSviewer to the data set, patterns built on mathematical relationships were uncovered and analyses such as keyword co-occurrence, citation analysis and co-citation analysis were performed [65].

4. RESULT AND DISCUSSION

4.1 What are the research trends in Reflective Intelligent Surface (RIS)-Enhanced Free Space Optics (FSO) according to the year of publication?

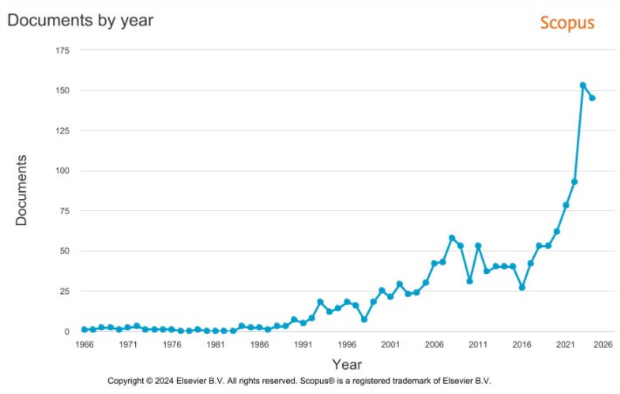

Figure 1. Plotting document publication by years

The trend in publications on Reflective Intelligent Surface (RIS)-Enhanced Free Space Optics (FSO) from 1966 to 2024, as shown in the figure, indicates a prolonged period of minimal research activity up until the early 2000s. During these initial decades, publications were sparse, reflecting the emerging state of both RIS and FSO technologies, which were likely limited by technological constraints and lack of practical applications. From around 2004, a gradual increase in research interest becomes noticeable, suggesting that foundational studies and theoretical explorations were being established. However, the growth in publications remained relatively steady and modest until approximately 2016, indicating a phase where early conceptual frameworks and small-scale experimental studies were likely prevalent. A sharp rise in publications is evident from 2017 onwards, peaking between 2022 and 2023. This significant increase corresponds with advancements in RIS and FSO technologies, as well as a growing recognition of their potential to address challenges in modern wireless communications, such as enhancing energy efficiency, signal reliability, and bandwidth utilization. The rapid increase in recent years highlights the heightened interest and investment in RIS-enhanced FSO research, driven by its relevance to evolving demands in high-performance communication systems. The continued upward trend into 2024 underscores the expanding research community's commitment to optimizing RIS-FSO integration for various applications, marking this field as a crucial area of innovation in next-generation communication technologies.

4.2 Who writes the most cited articles? and where do they work?

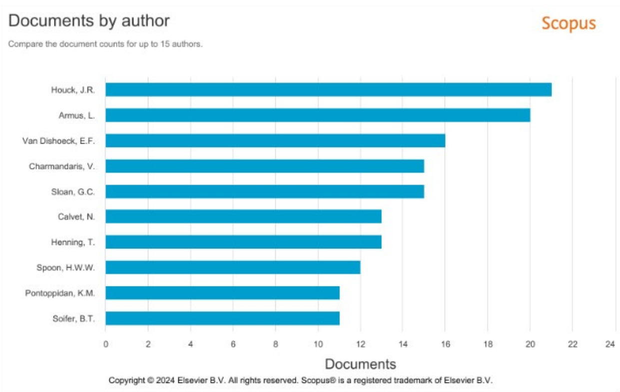

Figure 2. Bar Graph compare the document counts for up to 15 authors

The Bar Graph compare the document counts for up to 10 authors in the field of Reflective Intelligent Surface (RIS)-Enhanced Free Space Optics (FSO) highlights the prominent contributors driving research in this area. J.R. Houck leads the list with nearly 22 publications, followed closely by L. Armus, both of whom have established themselves as significant influencers through their extensive contributions. Their high document counts suggest a strong dedication to advancing RIS and FSO technologies, likely through foundational studies that explore new methodologies, applications, or theoretical insights. The consistent output from these authors reflects their sustained engagement with the field, setting a benchmark for future studies. Other notable contributors include E.F. Van Dishoeck and V. Charmandaris, each with a substantial number of publications. Their research contributions suggest that they play pivotal roles in addressing specific challenges within RIS-enhanced FSO systems. Given the complexities involved in RIS and FSO technologies, it is likely that these authors focus on various technical aspects, including signal processing, energy efficiency, and optimization of reflective surfaces. By contributing to these sub-domains, they add critical knowledge to the field, enabling other researchers to build upon their findings and explore RIS applications across diverse communication scenarios. Additionally, authors such as G.C. Sloan, N. Henning, and T. Spoon demonstrate significant contributions with document counts that indicate active involvement in collaborative research networks. These authors are likely part of interdisciplinary teams, working across different institutions or geographic regions to address complex RIS-enhanced FSO challenges that require a combined knowledge base. Their output emphasizes the collaborative nature of research in this domain, which benefits from shared expertise and resources. Collectively, these authors drive innovation in RIS-enhanced FSO by establishing key research themes, fostering global partnerships, and ensuring a steady flow of publications that contribute to the field's growth and evolution.

Table 3. The publication counts for the top 10 authors in this research area

Authors	Number of Document	Percentage %
Nguyen T.V.	49	3%
Ajam H.	27	2%
Kumar L.B.	24	2%
Saxena P.	14	1%
Chapala V.K.	11	1%
Sikri A.	17	1%
Aboagye S.	76	5%
Verma G.D.	27	2%
Wang S.	14	1%
Chapala V.K..	42	3%
Pang W.	15	1%
Han L.	15	1%
Boulogeorgos A.-A.	26	2%
Li X	10	1%

The data highlights the top authors in the field of Reflective Intelligent Surface (RIS)-Enhanced Free Space Optics (FSO), focusing on those with the highest citation counts and the most relevant publications to this study area. Nguyen T.V. stands out as a leading figure, with 49 documents, accounting for 3% of the total publications in this selection. This high output suggests Nguyen T.V.'s substantial contribution to advancing RIS-enhanced FSO technology, likely addressing core topics such as signal optimization, energy efficiency, and system resilience under various environmental conditions. The prominence of this author indicates an established expertise and an influential role in shaping research trends within this domain.

Other significant contributors include Aboagye S., with the highest number of documents at 76, representing 5% of the publications. This extensive body of work suggests a broad focus, possibly encompassing various aspects of RIS and FSO, from theoretical modelling to practical applications and system integration. Aboagye S.'s high output and percentage contribution underline the author's pivotal role in expanding the knowledge base of RIS-enhanced FSO, likely facilitating collaborative research initiatives and establishing foundational studies that other researchers can build upon. Authors like Ajam H., Verma G.D., and Boulogeorgos A.-A., each contributing between 2-3%, reflect a strong engagement with the field, likely focusing on specific sub-topics that complement and deepen understanding of RIS applications in FSO. The remaining authors, such as Chapala V.K., Kumar L.B., and Wang S., have lower individual document counts but still play essential roles, with each accounting for 1-2% of the total publications. These authors may focus on niche areas within RIS-enhanced FSO, contributing specialized insights that address emerging challenges or refine existing models. Their work helps diversify the research landscape, bringing varied approaches and perspectives that enrich the field. Overall, this group of researchers forms a robust collaborative network, pushing forward RIS-enhanced FSO studies by covering a range of topics from fundamental theory to applied technology, ensuring a well-rounded development in this fast-evolving field.

4.3 Who is the top 10 authors based on citation by research?

The bibliometric analysis from table 4 reveals the prominence of key researchers contributing significantly to the field of Reflective Intelligent Surface (RIS)-Enhanced Free Space Optics (FSO) from 2020 to 2024. Leading this list are authors like Wu Q. and Zhang R., whose 2019 paper on joint active and passive beamforming for intelligent reflecting surfaces in wireless networks has garnered a remarkable 2,981 citations. This high citation count highlights their foundational work in RIS, setting a robust basis for subsequent research in optimizing wireless networks through RIS. Similarly, Huang C. and colleagues have significantly influenced the field, with 2,562 citations on their study exploring the energy efficiency benefits of RIS in wireless communication, emphasizing the growing interest in sustainable and efficient communication systems driven by RIS technology. Di Renzo M., another prominent contributor, focuses on the potential of smart radio environments empowered by RIS, gaining 1,895 citations and showcasing the research community's recognition of RIS as a transformative force in wireless communications. The list also shows the collaborative nature and interdisciplinary approach in RIS research, with several authors, such as Debbah M., Yuen C., and Schober R., frequently contributing across multiple high-impact studies. Their work, alongside Guo H. and colleagues on weighted sum-rate maximization (664 citations) and Basar E. on new paradigms for 6G communications (581 citations), indicates a broadening focus toward optimizing RIS for next-generation networks. Notable contributions in specific areas include secure communications (Yu X. et al., 568 citations) and the application of RIS in UAV communication (Li S. et al., 493 citations). This diversity in research themes underscores RIS's versatility, providing critical insights for applications in areas such as beamforming optimization, energy efficiency, and enhanced wireless communication security. Collectively, these authors form the backbone of current advancements, guiding future studies toward overcoming remaining technical and practical challenges in RIS-enhanced FSO system

4.4 What are the map of Co-Authorship ?

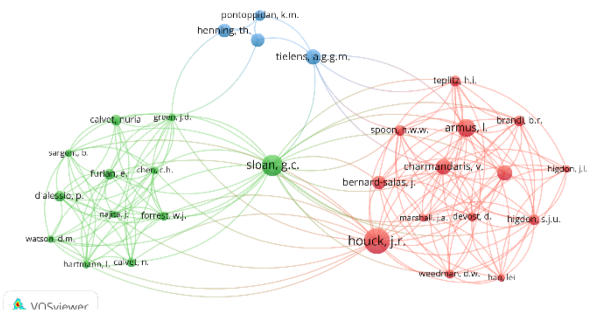

Figure 3. Network visualization map of co-authorship

The co-authorship data in the field of Reflective Intelligent Surface (RIS)-Enhanced Free Space Optics (FSO) reveals a range of influential contributors who have advanced this domain through collaborative research. Notably, J.R. Houck, with the highest number of documents (17) and a total link strength of 91, is a key figure in this field, suggesting substantial collaborative efforts and a significant role in advancing RIS-enhanced FSO research. Similarly, L. Armus, with 12 documents and a link strength of 68, has made considerable contributions, likely focusing on various aspects of RIS technology in FSO systems. The prominence of these authors reflects their active engagement in collaborative projects and their impact on shaping research directions in this specialized area. Other contributors, such as V. Charmandaris (10 documents, 70 link strength) and B.T. Soifer (10 documents, 65 link strength), also play critical roles within the collaborative network. Their high link strengths indicate extensive co-authorship with other researchers, contributing to the field's development by sharing expertise and resources. These authors have likely influenced RIS-enhanced FSO studies by exploring various technical challenges and applications, reinforcing the interdisciplinary nature of research in this area. The co-authorship data highlights the importance of collaboration, where shared insights and joint efforts drive innovation and comprehensive exploration of RIS applications in FSO systems.

Additional contributors with lower document counts, such as D. Devost (6 documents, 47 link strength) and H.W.W. Spoon (7 documents, 44 link strength), show that even authors with fewer publications can have significant collaborative influence. Their involvement reflects specialized contributions, possibly focusing on niche areas or addressing specific challenges within RIS-enhanced FSO. These authors' roles underscore the diverse range of expertise in the field, with each contributor bringing unique perspectives that enrich the collective understanding of RIS-FSO technology. The broad network of co-authorship illustrates a collaborative research ecosystem essential for tackling the complex challenges posed by RIS-enhanced FSO systems.

4.5 What are the popular keywords related to the study?

The analysis of keywords in RIS-enhanced FSO research highlights key themes and priorities shaping the field. High-frequency terms like "bit error rate" and "signal-to-noise ratio" emphasize the focus on improving signal quality and reducing transmission errors, which are critical for maintaining reliable communication in varying conditions. These terms show the central role of error reduction and signal enhancement strategies in recent studies.

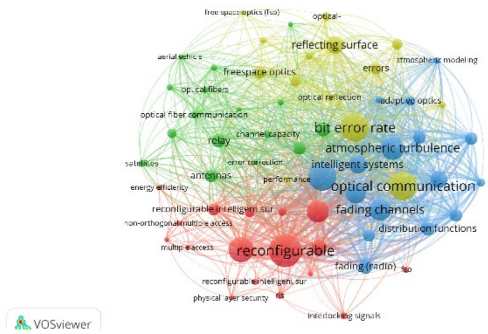

Figure 4. Network visualization map of keywords' co-occurrence

Keywords such as "atmospheric turbulence" and "fading channels" underscore the challenges posed by environmental factors that affect signal transmission, especially in outdoor and variable weather conditions. This indicates an active research focus on mitigating atmospheric interference to improve FSO performance. Other prominent terms, like "reconfigurable intelligent surfaces" and "adaptive optics," highlight the importance of RIS technology in enhancing FSO systems. Computational techniques such as "Monte Carlo methods" are frequently used to model and optimize RIS configurations, ensuring better efficiency and system performance. keywords like "energy efficiency" and "outage probability" reflect a growing commitment to developing sustainable, resilient FSO systems. These trends demonstrate the field's focus on practical and energy-efficient solutions, addressing the demands of next-generation wireless communication networks.

5. CONCLUSION

This bibliometric analysis demonstrates significant growth in research and collaboration in RIS-enhanced FSO systems, particularly since 2017, reflecting advancements in technology and growing interest in overcoming challenges like signal reliability, energy efficiency, and bandwidth utilization. The steady increase in publications highlights the alignment of this research with the evolving demands of next-generation communication systems. Key contributors have played a critical role in shaping the field, with highly cited works establishing a foundation for future studies. Their contributions address technical challenges, from signal optimization to secure communication, showcasing the interdisciplinary and collaborative nature of RIS research. The analysis also highlights important themes, including mitigating environmental effects like atmospheric turbulence, optimizing energy efficiency, and enhancing system performance. Popular keywords such as “signal-to-noise ratio” and “bit error rate” emphasize efforts to improve communication reliability. Overall, this study underscores the importance of RIS-enhanced FSO systems in driving innovation and delivering practical solutions for the challenges of future wireless communication networks.

Table 4. Top 10 authors based on citation by research

Authors	Title	Journal	Cited by
Wu Q.; Zhang R (2019).[66]	Intelligent Reflecting Surface Enhanced Wireless Network via Joint Active and Passive Beamforming	IEEE Transactions on Wireless Communications	2981
Huang C.; Zappone A.; Alexandropoulos G.C.; Debbah M.; Yuen C 2019.[67]	Reconfigurable intelligent surfaces for energy efficiency in wireless communication	IEEE Transactions on Wireless Communications	2562
Di Renzo M.; Zappone A.; Debbah M.; Alouini M.-S.; Yuen C.; De Rosny J.; Tretyakov S 2020.[68]	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	1895
Guo H.; Liang Y.-C.; Chen J.; Larsson E.G. 2020 [69]	Weighted Sum-Rate Maximization for Reconfigurable Intelligent Surface Aided Wireless Networks	IEEE Transactions on Wireless Communications	664
Basar E. 2020 [70]	Reconfigurable Intelligent Surface-Based Index Modulation: A New beyond MIMO Paradigm for 6G	IEEE Transactions on Communications	581
Yu X.; Xu D.; Sun Y.; Ng D.W.K.; Schober R 2020 .[71]	Robust and Secure Wireless Communications via Intelligent Reflecting Surfaces	IEEE Journal on Selected Areas in Communications	568
Yang Y.; Zheng B.; Zhang S.; Zhang R 2020 .[72]	Intelligent Reflecting Surface Meets OFDM: Protocol Design and Rate Maximization	IEEE Transactions on Communications	533
Abeywickrama S.; Zhang R.; Wu Q.; Yuen C. 2020 [73]	Intelligent Reflecting Surface: Practical Phase Shift Model and Beamforming Optimization	IEEE Transactions on Communications	511
Li S.; Duo B.; Yuan X.; Liang Y.-C.; DI Renzo M. 2020 [74]	Reconfigurable Intelligent Surface Assisted UAV Communication: Joint Trajectory Design and Passive Beamforming	IEEE Wireless Communications Letters	493
Mu X.; Liu Y.; Guo L.; Lin J.; Schober R (2022) .[75]	Simultaneously Transmitting and Reflecting (STAR) RIS Aided Wireless Communications	IEEE Transactions on Wireless Communications	395

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