Al-Qadisiyah JournalFor Engineering Sciences 18 (2025) 155 – 162

Contents lists available at: http://qu.edu.iq

Al-Qadisiyah Journal for Engineering Sciences

Journal homepage: https://qjes.qu.edu.iq

Review Paper

A systematic review of intelligent reflecting surface aided non-orthogonal multiple access beamforming-based free space optical communication systems

Batool Rafid Natiq and Lwaa Faisal Abdulameer

Department of Information and Communication, Al-Khwarizmi College of Engineering, University of Baghdad, Iraq.

ARTICLE INFO

Article history:
Received 17 June 2024
Received in revised form 07 October 2024
Accepted 25 May 2025

keyword:
Non-orthogonal multiple access (NOMA)
Orthogonal-multiple-access (OMA)
Intelligent-reflecting-surface (IRS)
Free-space-optical (FSO)
Radio-frequency (RF)

ABSTRACT

The intelligent reflecting surfaces (IRSs) that support non-orthogonal multiple access (NOMA), and using beamforming techniques in free space optical (FSO), are systematically reviewed in this study. The IRS improves the spectral efficiency and connection by guiding channel users more efficiently through reconfigurable reflecting elements. This enhancement makes it easier to apply NOMA even when the original channels are not aligned. The study emphasizes how hardware limitations like phase shifters with poor precision affect performance. A thorough analysis of previous studies on IRS varieties, beamforming strategies, and multiple access strategies is given. Additionally, the research gaps and potential future paths are also detailed. Background information on IRS types is one of the key contributions. Another major contribution is highlighting the advantages of combining IRS with beamforming and multiple access strategies in FSO communication systems.

1. Introduction

Recently, high speeds and low complexity of wireless communication environments have become increasingly essential[1]. High bandwidth, virtual reality, fast speed, and low power consumption, are some of the increasing connectivity requirements that 5G and beyond 5G (B5G)should have to address [2]. FSO communications are considered a potential alternative to offer quick data transfer rates.[3] It is used in a variety of situations, including supporting wireless networks for backhaul, acting as a backup for fiber, and assisting disaster recovery initiatives [4]. Additionally, FSO devices are inexpensive to reinstall and are readily transportable without requiring specialized fiber optic connections [5]. FSO offers 10 Gbps terrestrial Optical wireless communication (OWC). solutions, which is a higher data rate compared with other communications types like radio frequency communication (RF) [6]. Free space optics (FSO) is essential to modern wireless communications because it allows for the transmission of large bandwidths and remote access[7]. To meet the requirements of 5G and beyond, like high capacity and sufficient speed, FSO is a promising candidate. However, the buildings and trees are considered obstacles and limitations, therefore, line-of-sight (LOS) is essential in implementing the FSO link. In addition, many things affect the quality of FSO, such as the atmospheric-turbulence (AT), like fog and rain, mainly [8] 08, see Fig. 1. Additionally, FSO technology has certain fundamental drawbacks, such as little to no support for NLOS. No support or limited mobility [8]. FSO's performance might be enhanced by many methods like the hybrid models of dual-hop RF-FSO integrate the advantages of both FSO and RF communication technologies through the utilization of a relaying approach [9]. There are many types of research in this direction, which use hybrid RF-FSO technologies together [9–12]. Although using FSO/RF together has the advantage of helping to overcome the disadvantages of FSO, this solution will increase the complexity and cost of the system [12]. An intelligent-reflecting surface (IRS) can use passive components to reflect signals in the desired direction. Furthermore, it can overcome FSO's NLOS limitations, increase signal coverage, enhance channel conditions, and create virtual LOS [8, 13]. Hybrid FSO/RF communication systems using the RIS can further improve FSO performance [14]. We can improve the efficiency of the IRS by using it with multiple access methods like OMA, NOMA, and D-OMA, allowing organized resource sharing and mitigating interference [15]. Beamforming with IRS can increase SINR in FSO communication by addressing path loss, shadowing, and scattering, maximizing user signal power while minimizing interference [16, 17]. The main contributions of this paper include providing background on IRS types and the benefits of integrating IRS with multiple access techniques and beamforming in FSO systems. Additionally, the review offers a comprehensive analysis of current research on IRS types, multiple access techniques, and beamforming methods. It also points up research gaps and makes recommendations for possible future research studies. The research objectives of this study are as follows:

- Explain the role of IRS in enhancing spectral efficiency and connectivity in free-space optical (FSO) communication systems.
- Mention all types of IRS and the benefits with drawbacks of each type.
- Explain the types of multiple access techniques. Also understand how reconfigurable reflective elements can be used to steer user channels to improve NOMA implementation, even when the original channels are misaligned.
- Explain the types of beamforming strategies and understand how they can improve IRS performance.
- Review a range of research, clarifying the contributions and gaps of each research.

Finally suggesting a range of research directions to address some of these gaps.

*Corresponding Author.
E-mail address: lwaa@kecbu.uobaghdad.edu.iq ; Tel: (+964) 772 370-8900 (Lwaa Abdulameer)

https://doi.org/10.30772/qjes.2024.151005.1272

Nomenclature

AT	Atmospheric-turbulence	MEMS	Micro-electro-mechanical systems
B5G	Beyond 5G	NOMA	Non-orthogonal-multiple access
FSO	Free space optical	OIRS	Optical intelligent reflecting surfaces
IRSs	Intelligent reflecting surfaces	OWC	Optical wireless communication
LOS	Line-of-sight	RF	Frequency communication

By achieving these objectives, this study aims to enhance free space optical communication systems using IRS with beamforming and NOMA technologies. Additionally, it seeks to guide future research in this crucial area. This will provide valuable contributions to the field. The paper is structured as follows: the introduction of the paper is shown in section 1. Section 2 presents the background on IRS types, multiple access techniques, and beamforming methods. Section 3 provides a systematic literature review, and section 4 introduces new and future directions. Finally, section 5 presents a conclusion of the paper.

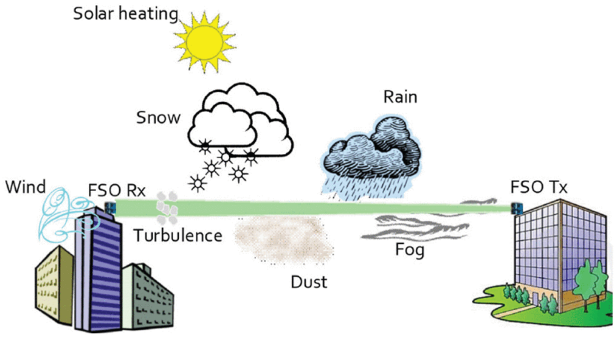


Figure 1. Environmental of FSO with atmosphere effects [18].

2. Background

This part presents IRS types, multiple access methods, and beamforming techniques.

2.1 IRS types

An RIS is an array of passive or active elements that reflect electromagnetic signals to reconfigure the wireless environment's propagation properties [19]. There are several types of IRSs: intelligent reflecting surface (IRS), which is a low-cost array of programmable reflecting components that can be passive or active, reconfigurable or non-reconfigurable [19]. Also, optical intelligent reflecting surfaces (OIRS), which enhance optical wireless communication capacity, are available as passive or active, reconfigurable or non-reconfigurable [20].

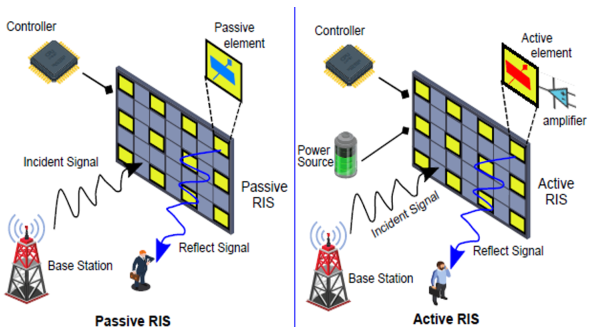


Figure 2. Types of IRSs [21].

2.2 STAR-IRS

Passive IRS, which is made of inexpensive electromagnetic materials. It is used in building facades, reconfigurable walls, highway poles, high-altitude platforms, glasses, billboards, and apparel [22], see Fig. 2. On the other hand, active IRS addresses the multiplicative fading effect by reflecting and amplifying signals using phase shift circuits and reflection-type amplifiers, though it consumes more power [23], see Fig. 2. Active IRS converts multiplicative channel loss to an additive form, and a hybrid design of active and passive IRS could optimize performance. However, power consumption without a grid connection remains a concern, necessitating further research [17]. Also, we discern two categories of IRS, and OIRS: designs based on mirrors and designs based on meta-surface-based, each one of which can be done in two ways. *First*, for designs based on mirrors, mirrors are common reflecting components in optical systems. Because they can only support specular reflection, they must mechanically adjust their orientation to refract the light in the intended direction [24]. This can be done in the two following: i) The first way is standard mirrors, which are used to guide the beam's reflection and rely on reorienting a single flat mirror via a mechanical rotational gimbal structure driven by electrical motors [25]. This approach is economical and straightforward to analyze with geometric optics. It provides a foundation for the study of more complex optical-reflecting surfaces. However, deploying large mirrors is challenging, particularly on building walls, due to the significant space required for reorientation and their large form factor. Moreover, mirrors are limited to specular reflection, lacking the ability to alter the reflected beam's properties in other ways, see Fig. 3a.

ii) The second way of designing based on mirrors is Micro-mirror surfaces, or micro-electro-mechanical systems (MEMS) mirrors, consisting of tiny, repositionable mirror plates. Their small size allows for easy deployment on building walls without significantly altering the form factor [26]. Each micro-mirror can be independently controlled for features like collimating and focusing beams, though they still have limitations in adjusting the reflected-beam wavefront, see Fig. 3b.

The second category is meta-surface-based designs, meta-surface-based IRSs use subwavelength unit cells to modify the phase, amplitude, and polarization of reflected waves [19]. Optical meta-surfaces, operating at optical frequencies with nano-scale technologies, differ from traditional RF technologies.

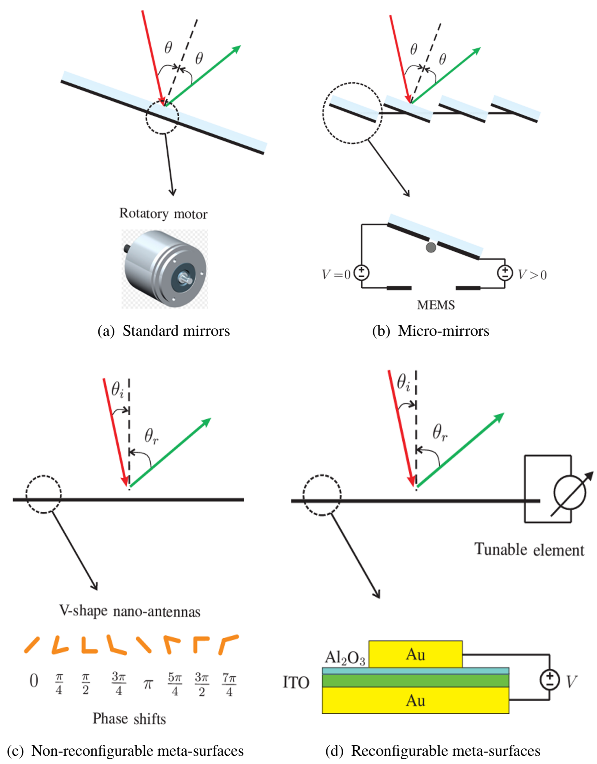


Figure 3. Four configurations (a,b) Standard and micro mirrors; (c,b) Non-reconfigurable and reconfigurable meta-surfaces [27].

We examine two main classes of meta-surfaces and optical meta-surfaces. Non-reconFigureurable-metasurfaces, initially, static nano-scale scatterers, or nano-antennas, were assembled with specific optical characteristics after fabri-

cation to create optical meta-surfaces. The core physical principle is that the shape, size, and angular orientation of these nano-antennas directly influence the properties of the reflected wave. In particular, the principles of reflection and refraction were first demonstrated using V-shaped optical nano-antennas in the mid-infrared region of the electromagnetic spectrum. By adjusting the angle and orientation of the legs of these V-shaped nano-antennas, a full 360-degree phase shift can be achieved. Additional phase-shifting mechanisms have also been proposed in the literature, such as the Pancharatnam-Berry phase change, which is accomplished by rotating anisotropic scatterer elements and varying the sizes of isotropic metallic nano-patch antennas. Although these meta-surfaces cannot be reconfigured, they can still be valuable in fixed-transceiver FSO systems where mobility is not required [28] see Fig. 3c.
The second one is reconfigurable-meta-surfaces, most reconfigurable metasurfaces use materials with optical characteristics modifiable by external mechanical, electrical, thermal, or optical stimuli [29]. Increasing the number of IRS and meta-atoms boosts gain and performance, depending on the application and communication system architecture [14], see Fig. 3d.
Reconfigurable intelligent surfaces (IRS) capable of simultaneous transmission and reflection, known as STAR-IRS, are increasingly prevalent. STAR-IRS can reflect and refract signals, providing complete wireless coverage and serving users on both sides of the transmitter. Unlike traditional IRS, which only reflects signals to users on the same side [30, 31]. This solves the limitation of traditional IRS, which cannot be used when the transmitter and receiver are on different sides. For an IRS to operate, its transmitter and receiver need to be on the same side, as it can only reflect signals directed towards it, limiting it to a half-space [32]. This placement often restricts flexibility and efficacy, to overcome this, STAR-IRS was proposed [33]. It can simultaneously reflect and transmit signals by splitting the incoming signal into two parts: one part is sent, and the other is reflected, providing 360-degree coverage [30]. Creating an operational STAR-IRS may be a critical first step toward achieving complete coverage, see Fig. 4 and Table 1.

Table 1. Protocols of STAR-RIS [28].

No.	Items	Passive RIS	Active RIS	STAR-RIS
1	Coverage	180	180	360
2	Elements	Passive	Active	Passive / Active
3	Hardware design	Simple	Complicated	Complex with MS, ES, and TS operation modes
4	Working	Reflect signal	Reflect signal	Reflect and transmit signal
5	Path loss	Multiplicative	Additive	Multiplicative / Additive

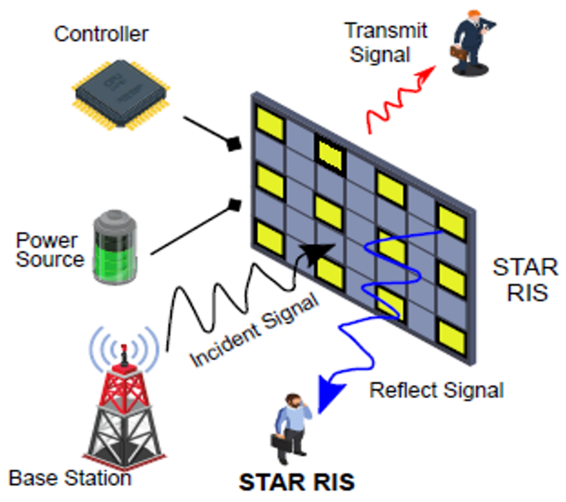
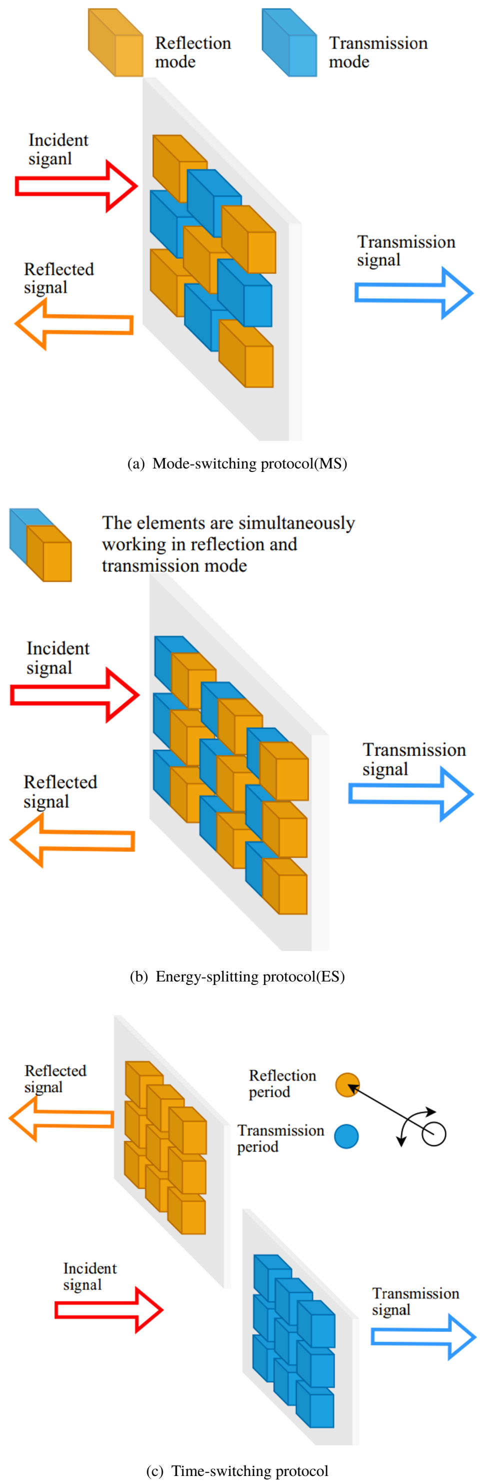


Figure 4. Scenario of STAR-IRS [23].

There are protocols for STAR-IRS that specify how STAR-IRS can operate [21]:
Mode switching (MS), in which the STAR-RIS elements switch between transmitting (T) and reflecting (R) modes using ön/off”protocols. It optimizes mode choice and phase shifts but with limited gains. Energy splitting (ES), in which all elements split energy between T and R modes, offering design flexibility but creating significant configuration overhead. Finally, time switching (TS), in which elements alternate between T and R modes at different times, simplifies TARCs but requires strict synchronization and increases hardware complexity, see Fig. 5 and Table 2.



(a) Mode-switching protocol(MS)

(b) Energy-splitting protocol(ES)

(c) Time-switching protocol

Figure 5. (a) Mode-switching protocol(MS); (b) Energy-splitting protocol(ES); (c) time-switching protocol(TS) [34].

STAR-IRS has many benefits and applications. It can transmit and reflect signals, providing coverage on both sides, and is suitable for windows due to its transparency. Enhances wireless coverage by bypassing obstacles like buildings and trees. It improves communication by bridging interior and exterior spaces, beneficial for mmWave and THz communications. It also reduces propagation distance and increases signal strength with single-hop full-space coverage. It enhances physical layer security (PLS) by providing full-space propagation, reducing eavesdropping risk. It improves positioning and sensing in buildings and intelligent factories, enhancing data transfer and robot placement [21], see Fig. 6. Despite the benefits mentioned above, the primary problem with using just IRS or STAR-IRS is signal interference among different users, resulting in poor signal quality and increased error rates [34]. Resource management becomes inefficient, leading to imbalanced spectrum utilization and reduced overall network performance. Spectral efficiency drops as simultaneous usage by multiple users is not optimized. Quality of Service (QoS) deteriorates, making it challenging to meet diverse user requirements for data rates and latency. Network scalability issues arise, complicating the inclusion of more users, and the ability to offer varied services is hindered, impacting the overall user experience. Using multiple access techniques will solve these problems.

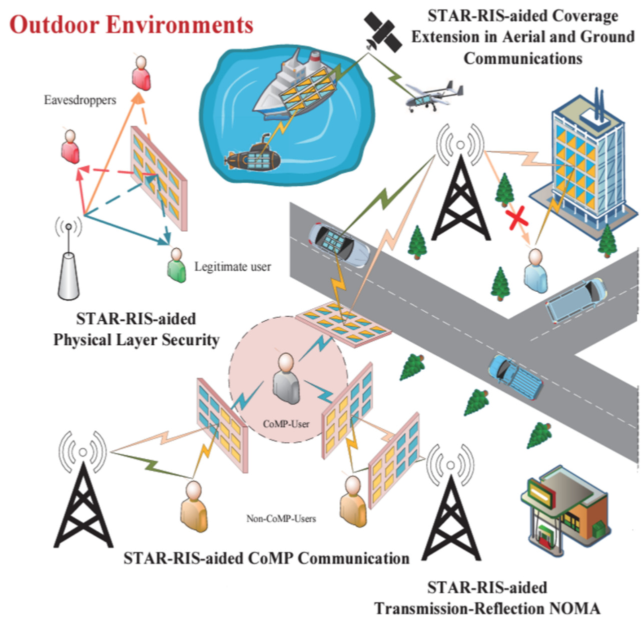


Figure 6. Application scenarios of STAR-IRS networks [28].

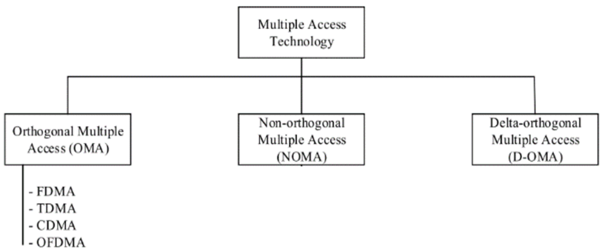


Figure 7. Multiple access technologies [35].

2.3 multiple access techniques

Multiple access schemes increase network capacity, improve spectrum efficiency, provide wider coverage, enhance user experience, and support delivering services with varying quality levels [36]. Figure 7 presents an overview of several access technologies.

2.3.1 OMA

Orthogonal multiple access (OMA) techniques enable multiple users to share resources orthogonally via time, frequency, or code division [36]. Orthogonal frequency division multiple access (OFDMA) splits data into parallel sub-streams, each sent on different subcarriers. This provides high spectral efficiency and resistance to selective fading, inter-symbol interference (ISI), and multipath effects [37]. Time division multiple access (TDMA) allocates a time slot to each user's data stream [38]. By assigning unique codes, code division multiple access (CDMA) allows concurrent transmission for all users in the same frequency band. CDMA with direct sequence spread spectrum (DS-CDMA) is the most common model [39]. OFDMA and Single carrier FDMA (SC-FDMA) (a pre-DFT encoded version of FDMA) offer advantages like multipath robustness and simpler frequency equalization, making them preferred for long-term evolution (LTE's) physical layer [39].

2.3.2 NOMA

Non-orthogonal multiple access (NOMA) enables multiple customers to share frequency sources and transmit data simultaneously [40]. It reduces latency and improves spectral efficiency, either by transmitting the same frequency with different capacities or by code allocation [41]. NOMA's ability to support multiple users sharing the same time and frequency resources makes it critical for 5G and 6G networks [42] It uses overlay encoding and sequential interference cancellation (SIC) for multiple users in the power domain, enabling efficient resource utilization [43].

2.3.3 D-OMA

It is a new multi-access method for 6G that uses partially overlapping subbands for the NOMA cluster increasing outage capacity and security in wireless networks [44].
Research shows that combining OMA or NOMA with IRS or STAR-IRS can support next-generation networks by adding variable spectrum efficiency, flexible resource allocation, and greater network coverage [45, 46]. STAR-IRS with transmission-imaging NOMA can increase NOMA utility by adjusting transmitted and reflected channel conditions [47]. Using intelligent reflecting surfaces (IRS) with multiple access techniques but without beamforming can lead to several issues. The signal direction becomes less precise, causing increased signal loss and interference among users. This will degrade signal quality and raise error rates. Energy efficiency drops as higher power is needed to reach users, and network coverage suffers due to ineffective signal targeting. Additionally, the network struggles to adapt to environmental changes, leading to service quality degradation, and experiencing higher latency. Negatively impacting user experience, particularly in latency-sensitive applications [48–52].

Table 2. Comparison of types of IRS [23].

No.	Protocol	Optimization Variables	Advantages	Disadvantages
1	ES	for each transmission and reflection element, there are amplitude and phase shift coefficients.	Flexible.	A large number of design variables.
2	MS	T mode for transmission phase shift coefficients, and R mode for reflection phase shift coefficients.	implement easily.	Reduced the gain of transmission and reflection.
3	TS	Transmission phase shift coefficients of each element during the T period, reflection phase shift coefficients of each element during the R period.	Independent T and R design.	High implementation complexity in hardware component.

2.4 Beamforming techniques

For 5G and beyond, users need data rates of 5 to 50 Gbps for low and high mobility respectively. Beamforming in 5G is a key technique using narrow beam-width radiation patterns. It is used to cover intended users/directions, enhance energy efficiency, reduce power consumption, improve spectral efficiency, and increase system security [48] see Fig. 8. There are many types of beamforming [16].

- Switched beamforming: uses a set of fixed beams, choosing the best one based on criteria, optimizing signal reception without real-time computations [53].
- Adaptive beamforming: dynamically adjusts beam patterns to the signal environment. It includes, [16]:
  - Non-blind adaptive beamforming: uses pilot/reference signals to optimize the beam.
  - Blind adaptive beamforming: adjusts beam patterns based on statistical characteristics without reference signals.
- Analog beamforming: utilizes phase shifters and amplitude adjustments in the analog domain, being simpler and less costly [54].
- Digital beamforming: processes signals digitally for precise and flexible beam pattern [54].
- Hybrid beamforming: combines analog and digital techniques for a balance of cost and performance [54].

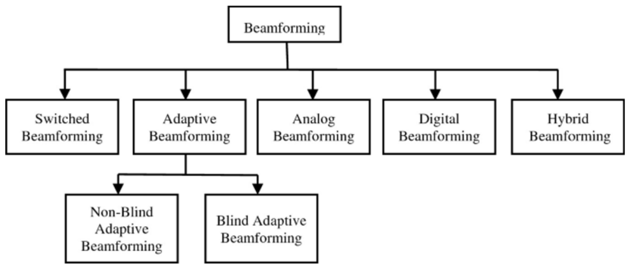


Figure 8. Beamforming techniques [16].

These methods enhance wireless communication by increasing system capacity, reducing interference, and improving signal quality. Various research explores integrating IRS with beamforming techniques [14, 47, 48, 53, 54]. There is no research on using beamforming with STAR-RIS, also, there is no research on using STAR-RIS in FSO. As a result, combining beamforming with STAR-RIS and NOMA in free space optics (FSO) systems enhances spectrum efficiency by allowing multiple users to share the same resources simultaneously. Beamforming precisely directs signals, reducing interference and improving signal quality. It also boosts energy efficiency by focusing signals on target users, reducing power loss. STAR-RIS improves coverage and reliability in challenging environments, while the integration of NOMA and FSO increases data transmission rates. Additionally, this combination mitigates environmental interference, enhancing the stability and quality of the communication link.

3. literature review

In 2020 [45], the integration of IRS with NOMA enhanced spectral efficiency and connectivity by directing user channels with IRS and beamforming. The study shows improved performance but faces several gaps: it assumes that between the cell edge and base station, there are no direct link users, which limits generalizability. Finite-resolution phase shifters cause performance degradation, necessitating new hardware solutions. It primarily focuses on single-user scenarios, requiring more detailed multi-user models. Path loss significantly affects performance at lower transmission powers, highlighting the need for optimized IRS placement and power allocation strategies.
In 2021, [14] a novel hybrid RF/FSO method using IRS, where free space optical (FSO) communication is used in the first hop and the IRS with radio frequency communication uses the second hop. It shows performance gains of 25–50 dB depending on the number of reflectors (N = 16 to N = 256). Despite advancements, the study has several gaps: it does not evaluate RIS impact in scenarios with direct links between the base station and cell-edge users, limiting generalizability. Practical implementation of RIS with finite phase shifts results in performance degradation, requiring improved hardware solutions. It primarily focuses on single-user scenarios, necessitating more detailed multi-user evaluations. Path loss significantly affects performance, especially at lower transmission powers, underscoring the need for optimized IRS placement and power allocation strategies.
In 2021, [55] the research improves multi-link free space optical (FSO) systems using intelligent reflecting surfaces (IRS) to overcome line-of-sight (LOS) limitations. It introduces three protocols (time division, IRS division, and IRS homogenization) and a model to enhance the bit error rate (BER) and outage probability. While simulations show gains, limitations include reliance on theoretical models, ideal IRS assumptions, and complex optimization algorithms. Future work should focus on practical testing, hardware issues, and real-time algorithm development.
In 2022, [46] research on the physical layer security of a heterogeneous visible light communication (VLC) and radio-frequency (RF) cooperative NOMA network enhanced by RIS. RIS aims to improve resistance to eavesdropping by optimizing signal direction, extending coverage, and enhancing quality of service. A closed-form expression for the secrecy outage probability (SOP) demonstrates better performance than traditional VLC-RF multi-hop AF relay networks. Gaps include reliance on idealized models that may not fully reflect real-world conditions. A primary focus is on single-user scenarios, which are inadequate for practical environments with multiple users. Heavy dependence on RIS for secure beamforming, requires more integrated solutions. Finally, a lack of comprehensive studies addressing the combined effects of multiple simultaneous attacks.
In 2022, [47] a study investigated the power minimization problem for an uplink NOMA system empowered by STAR-RIS, providing 360-degree coverage. The joint optimization scheme for user transmits power, transmission and reflection beamformers, and time allocation demonstrates better performance than existing methods. However, the research faces gaps: heavy reliance on idealized models and theoretical simulations that may not fully capture real-world conditions. A primary focus on single-user scenarios, neglecting multi-user complexities. Finally, the practical challenges of deploying STAR-RIS, such as phase shift imperfections and environmental impacts, are not comprehensively addressed.
In 2023, [15] research on integrating IRS in 6G wireless systems focuses on adapting and optimizing multiple access schemes like TDMA, FDMA, and NOMA for IRS-aided multi-user systems. The study demonstrates significant performance enhancements but identifies gaps: the lack of frequency-selective reflection and the complexity of joint optimization of beamforming and reflection. Also, the hardware constraints limit phase shift adjustments and challenges in managing inter-user interference.
In 2023, [56] the integration of IRS and NOMA enhances physical-layer security in wireless communication networks for both downlink and uplink scenarios. IRS improves spectrum and energy efficiency, while NOMA boosts spectrum efficiency. The study identifies key performance metrics like connection outage probability (COP), secrecy outage probability (SOP), and average secrecy rate (ASR). Gaps include a lack of analysis of the Nakagami-m fading channel and uplink scenarios, which the study aims to fill.
In 2023, [57] a novel system enhances the secrecy of uplink communications in heterogeneous networks using RIS and a mix of RF and FSO links. The system uses a Gamma-Gamma distribution to model atmospheric turbulence for the FSO link and Rayleigh and Nakagami-m distributions for legitimate and wiretap RF links, respectively. Closed-form expressions for key metrics show superior secrecy performance compared to traditional methods. Gaps include insufficient focus on the security of mixed RF/FSO systems and the absence of enhancements for vulnerable RF links. Further analysis under different channel conditions and broader system configurations is needed to validate the proposed model's effectiveness.
In 2023,[20] research on the performance of optical IRS (OIRS) and Planar Mirror Surface (PMS)-assisted underwater wireless optical communication (UWOC) systems provides a detailed analysis of key metrics. It shows significant performance improvements over conventional NLOS UWOC systems. Gaps include not accounting for the dynamic nature of underwater environments, such as water currents and varying sea conditions. Limited investigation of adaptive placement strategies. Finally, assumptions of ideal conditions for OIRS and PMS operation without considering potential practical issues like mechanical failures or alignment inaccuracies.
In 2024, [58] the design and performance of the dual simultaneously transmitting-and-reflecting reconfigurable-intelligent-surface (D-STAR) system. It provides 360-degree full-plane coverage for uplink and downlink wireless communications. The study shows enhanced performance and reduced inter-user interference compared to conventional single RIS and half-duplex networks. Gaps include reliance on theoretical models and simulations without practical validation. Its assumptions about ideal RIS operations may not hold in practice. Also, the complexity and computational overhead of optimization algorithms for dynamic configurations are not being adequately addressed. Future work should focus on empirical testing, addressing practical deployment challenges, and developing efficient algorithms for real-world applicability.

4. New and future directions

Future research on IRS and RIS technologies should focus on addressing practical limitations and enhancing robustness. Key areas include developing hardware solutions to mitigate performance degradation from finite-resolution phase shifters and hardware impairments.
Also, optimizing IRS placement and power allocation to reduce path loss effects, and improving real-world validation through multi-user scenario evaluations. Advanced algorithms for dynamic configurations, secure and efficient beamforming techniques, and adaptive placement strategies, especially in dynamic environments. This like underwater communication and high-mobility applications, are essential. Integrating AI and machine learning for optimization, enhancing physical layer security, and addressing multiple attacks and hardware imperfections are critical. Practical testing under varied channel conditions and system configurations is necessary to fully harness the potential of IRS, RIS, and STAR-IRS technologies in 6G networks and beyond [59]. For STAR-IRS technology, future research should focus on the joint design of analog and digital beamforming to enhance coverage and performance. It should also ensure accurate channel state information (CSI), and assess multi-user NOMA networks with faulty successive interference cancellation (SIC) and CSI. Properly placing STAR-IRS relative to transmitters and users, balancing transmitters and reflection capabilities, and developing hybrid algorithms to

manage transmission-image beamforming complexity are important for improved flexibility in integrating STAR-IRS with UAVs for operation in dynamic environments. Adaptive mechanisms are also needed, leveraging AI and machine learning for the optimization of dynamic STAR-IRS for high-mobility applications such as vehicular networks. These applications pose challenges such as high noise levels, doppler shift, and increased signal Overhead for real-time CSI monitoring. In addition, STAR-IRS RF can enable better sensing and localization. However, optimizing the integration of machine learning, compressed sensing, and analog beamforming is essential. Finally, using beamforming with multiple access methods in combination with free space optical (FSO) communications systems of STAR-IRS can significantly improve performance. Research in these ways remains largely unexplored and offers great opportunities for future innovation [21].

5. Conclusions

This paper provides a review of intelligent reflecting surfaces (IRS) with non-orthogonal multiple access (NOMA) in free space optical (FSO) conversation systems. It also emphasizes the giant capacity for reinforcing spectral performance, connectivity, and general network performance. IRS correctly directs person channels, facilitating the implementation of NOMA, even in non-aligned unique channel scenarios. Despite the promising results, the look identifies several gaps, including the need for new hardware answers to address finite-resolution segment shifter constraints. Additionally, there is a need for more comprehensive multi-consumer critiques and optimized IRS placement and energy allocation strategies to mitigate course loss. Future studies ought to consider developing superior algorithms for dynamic configurations, and secure and green beamforming strategies. Realistic checking under varied conditions is also essential to fully harness the potential of IRS-NOMA technologies in next-generation wireless communication networks.

Authors' contribution

All authors contributed equally to the preparation of this article.

Declaration of competing interest

The authors declare no conflicts of interest.

Funding source

This study didn't receive any specific funds.

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

REFERENCES

[1] M. A. Atiyah, L. F. Abdulameer, and G. Narkhedel, "Pdf comparison based on various fso channel models under different atmospheric turbulence," *Al-Khwarizmi Engineering Journal*, vol. 19, no. 4, p. 78–89, Aug 2023. [Online]. Available: https://doi.org/10.22153/kej.2023.09.004

[2] M. J. Al-Dujaili and M. A. Al-dulaimi, "Fifth-generation telecommunications technologies: Features, architecture, challenges and solutions," *Wirel Personal Commun*, vol. 128, no. 1, p. 447–469, 2023. [Online]. Available: https://doi.org/10.1007/s11277-022-09962-x

[3] A. A. Abdullah, "Study the effect of iraqi weather parameter in fso communication using different wavelength (650, 532) nm," *Iraqi Journal of Physics,*, vol. 16, no. 36, p. 104–112, 2018. [Online]. Available: https://doi.org/10.30723/ijp.v16i36.35

[4] E. Zedini, H. Soury, and M. Alouini, "On the performance analysis of dual-hop mixed fso/rf systems," *IEEE Trans Wirel Commun*, vol. 15, no. 5, p. 3679–3689, 2016. [Online]. Available: https://doi.org/10.1109/TWC.2016.2524685

[5] A. A. Khaskheli and F. A. Memon, "Performance evaluation of digital modulation techniques for next generation fso," *International Journal of Advanced Studies in Computers Science and Engineering*, vol. 9, no. 1, p. 1–5, 2020. [Online]. Available: https://www.new.ijascse.org/Digital_Modulation_Techniques.pdf

[6] D. Rodewald, "Mrv introduces industry's first 10g ethernet wireless point-to-point system," *MRV Communications, Inc*, vol. 2, no. 2, pp. 394–412, 2008. [Online]. Available: https://us.aving.net/news/articleView.html?idxno=13940

[7] L. F. Abdulameer and H. Fadhil, "Performance analysis of fso under turbulent channel using ostbc," *Al-Nahrain Journal for Engineering Sciences (NJES)*, vol. 21, no. 3, p. 344–349, 2018. [Online]. Available: http://doi.org/10.29194/NJES.21030344

[8] G. K. T. N. Do, T. L. Nguyen, D. B. D. Costa, and Z. J. Haas, "Multi-ris-aided wireless systems: Statistical characterization and performance analysis," *IEEE Transactions on Communications*, vol. 69, no. 12, p. 8641–8658, 2021. [Online]. Available: https://doi.org/10.1109/TCOMM.2021.3117599

[9] I. I. Kim and E. J. Korevaar, "Availability of free-space optics (fso) and hybrid fso/rf systems," *in Optical Wireless Communications IV, SPIE*, vol. 4520, no. 4, p. 84–95, 2001. [Online]. Available: https://doi.org/10.1117/12.449800

[10] F. Nadeem, V. Kvicera, M. S. Awan, E. Leitgeb, S. S. Muhammad, and G. Kandus, "Weather effects on hybrid fso/rf communication link," *IEEE journal on selected areas in communications*, vol. 27, no. 9, p. 1687–1697, 2009. [Online]. Available: https://doi.org/10.1109/JSAC.2009.091218

[11] M. Usman, H.-C. Yang, and M.-S. Alouini, "Practical switching-based hybrid fso/rf transmission and its performance analysis," *IEEE Photonics J*, vol. 6, no. 5, p. 1–13, 2014. [Online]. Available: http://doi.org/10.1109/JPHOT.2014.2352629

[12] B. Bag, A. Das, I. S. Ansari, A. Prokeš, C. Bose, and A. Chandra, "Performance analysis of hybrid fso systems using fso/rf-fso link adaptationed," *IEEE Photonics J*, vol. 10, no. 3, pp. 1–17, 2019. [Online]. Available: https://doi.org/10.1109/JPHOT.2018.2837356

[13] Q. Wu, S. Zhang, B. Zheng, C. You, and R. Zhang, "Intelligent reflecting surface-aided wireless communications: A tutorialp," *IEEE transactions on communications*, vol. 69, no. 5, p. 3313–3351, 2021. [Online]. Available: https://doi.org/10.1109/TCOMM.2021.3051897

[14] G. Alnwaimi and H. Boujemaa, "Hybrid rf/fso communications through reconfigurable intelligent surfaces in the presence of pointing errors," *Telecommun Syst*, vol. 78, no. 2, p. 155–162, 2021. [Online]. Available: https://doi.org/10.1007/s11235-021-00802-0

[15] W. Jiang and H. D. Schotten, "Orthogonal and non-orthogonal multiple access for intelligent reflection surface in 6g systems," *in 2023 IEEE Wireless Communications and Networking Conference (WCNC), IEEE*, vol. 1, pp. 1–6, 2023. [Online]. Available: https://doi.org/10.1109/WCNC55385.2023.10118706

[16] E. Ali, M. Ismail, R. Nordin, , and N. F. Abdulah, "Beamforming techniques for massive mimo systems in 5g: overview, classification, and trends for future research," *Frontiers of Information Technology Electronic Engineering*, vol. 18, no. 1, p. 753–772, 2017. [Online]. Available: https://doi.org/10.1631/FITEE.1601817

[17] X. Mu, Y. Liu, L. Guo, J. Lin, , and N. Al-Dhahir, "Exploiting intelligent reflecting surfaces in noma networks: Joint beamforming optimization," *IEEE Trans Wirel Commun*, vol. 19, no. 10, p. 6884–6898, 2020. [Online]. Available: https://doi.org/10.1109/TWC.2020.3006915

[18] A. Trichili, A. Ragheb, M. A. Esmail, M. Altamimi, I. Ashry, B. S. Ooi, S. Alshebeili, and M. Alouini, "Retrofitting fso systems in existing rf infrastructure: A non-zero-sum game technology," *IEEE Open Journal of the Communications Society*, vol. 2, p. 2597–2615, 2021. [Online]. Available: https://doi.org/10.1109/OJCOMS.2021.3130645

[19] M. D. Renzo, A. Zappone, M. Debbah, M. Alouini, and C. Yuen, "Smart radio environments empowered by reconfigurable ai meta-surfaces: An idea whose time has come," *EURASIP Journal on Wireless Communications and Networking; New*, vol. 2019, no. 1, p. 1–20, 2019. [Online]. Available: https://doi.org/10.1186/s13638-019-1438-9

[20] R. Salam, A. Srivastava, V. A. Bohara, and A. Ashok, "An optical intelligent reflecting surface-assisted underwater wireless communication system," *IEEE Open Journal of the Communications Society*, vol. 4, pp. 1774–1786, 2023. [Online]. Available: https://doi.org/10.1109/OJCOMS.2023.3303190

[21] M. Ahmed, A. Wahid, S. S. Laique, W. U. Khan, A. Ihsan, F. Xu, S. Chatzinotas, and Han, "A survey on star-ris: Use cases, recent advances, and future research challenges," *JTechRxiv.*, no. 1, p. 107204, 2023. [Online]. Available: https://doi.org/10.36227/techrxiv.21820617.v1

[22] J. Lončar and Z. Šipuš, "Challenges in design of power-amplifying active metasurfaces," *in 2020 International Symposium ELMAR, IEEE*, p. 9–12, 2020. [Online]. Available: https://doi.org/10.1109/ELMAR49956.2020.9219017

[23] Z. Zhang, L. Dai, X. Chen, C. Liu, F. Yang, R. Schober, and H. V. Poor, "Active ris vs. passive ris: Which will prevail in 6g?" *IEEE Transactions*

on Communications, vol. 71, no. 3, p. 1707–1725, 2023. [Online]. Available: https://doi.org/10.1109/TCOMM.2022.3231893

[24] B. Zheng, Q. Wu, and R. Zhang, "Intelligent reflecting surface-assisted multiple access with user pairing: Noma or oma?" *IEEE Communications Letters*, vol. 24, no. 4, p. 753–757, 2020. [Online]. Available: https://doi.org/10.1109/LCOMM.2020.2969870

[25] M. A. Khalighi and M. Uysal, "Survey on free space optical communication: A communication theory perspective," *IEEE communications surveys tutorials*, vol. 16, no. 4, p. 2231–2258, 2014. [Online]. Available: https://doi.org/10.1109/COMST.2014.2329501

[26] Q. Wu and R. Zhang, "Intelligent reflecting surface enhanced wireless network via joint active and passive beamforming," *IEEE Trans Wirel Commun*, vol. 18, no. 11, pp. 5394–5409, 2019. [Online]. Available: https://doi.org/10.1109/TWC.2019.2936025

[27] V. Jamali, H. Ajam, M. Najafi, B. Schmauss, R. Schober, and H. V. Poor, "Intelligent reflecting surface assisted free-space optical communications," *IEEE Communications Magazine*, vol. 59, no. 10, p. 57–63, 2021. [Online]. Available: https://doi.org/10.1109/MCOM.001.2100406

[28] Y. Liu, X. Liu, X. Mu, X. Lin, O. Alhussein, and J. Yuan, "Star: Simultaneous transmission and reflection for 360° coverage by intelligent surfaces," *IEEE Wirel Commun*, vol. 28, no. 6, p. 102–109, 2021. [Online]. Available: https://doi.org/10.1109/MWC.001.2100191

[29] J. W. Goodman, "Introduction to fourier optics. roberts and company publishers," *Experimental Thermal and Fluid Science*, vol. 34, no. 6, 2005.

[30] D. Wang, C. Watkins, , and H. Xie, "Mems mirrors for lidar: A review," *Micromachines (Basel)*, vol. 11, no. 5, p. E456, 2020. [Online]. Available: https://doi.org/10.3390/mi11050456

[31] K. Zhao, Y. Mao, , and Y. Shi, "Simultaneously transmitting and reflecting reconfigurable intelligent surfaces empowered cooperative rate splitting with user relaying," *Entropy*, vol. 26, no. 12, p. 1019, 2024. [Online]. Available: https://doi.org/10.3390/e26121019

[32] K. Zhi, C. Pan, H. Ren, K. K. Chai, and M. Elkashlan, "Active ris versus passive ris: Which is superior with the same power budget?" *IEEE Communications Letters*, vol. 26, no. 5, p. 1150–1154, 2022. [Online]. Available: https://doi.org/10.1109/LCOMM.2022.3159525

[33] W. Long, R. Chen, M. Moretti, W. Zhang, and J. Li, "A promising technology for 6g wireless networks: Intelligent reflecting surfacep," *Journal of Communications and Information Networks*, vol. 6, no. 1, p. 1–16, 2021. [Online]. Available: https://doi.org/10.23919/JCIN.2021.9387701

[34] Y. Ma, L. Chen, T. Lu, Y. Song, , and K. Cao, "Star-ris-assisted key generation method in quasi-static environment," *EURASIP J Wirel Commun Netw*, vol. 55, no. 2024, 2024. [Online]. Available: https://doi.org/10.1186/s13638-024-02388-y

[35] A. F. M. S. Shah, A. N. Qasim, M. A. Karabulut, H. Ilhan, and M. B. Islam, "Survey and performance evaluation of multiple access schemes for next-generation wireless communication systems," *IEEE Access*, vol. 9, no. 3, p. 113428–113442, 2021. [Online]. Available: https://doi.org/10.1109/ACCESS.2021.3104509

[36] Y. Al-Eryani and E. Hossain, "The d-oma method for massive multiple access in 6g: Performance, security, and challenges," *IEEE Vehicular Technology Magazine*, vol. 14, no. 3, p. 92–99, 2019. [Online]. Available: https://doi.org/10.1109/MVT.2019.2919279

[37] J. Li, X. Wu, and R. Laroia, "Ofdma mobile broadband communications: A systems approach," *Cambridge University Press*, no. 4, 2013. [Online]. Available: https://doi.org/10.1017/CBO9780511736186

[38] V. Garg, "Wireless communications networking(book)," *Elsevier*, no. 4, 2007. [Online]. Available: https://doi.org/10.1016/B978-0-12-373580-5.X5033-9

[39] A. F. M. S. Shah, A. N. Qasim, M. A. Karabulut, H. Ilhan, and M. B. Islam, "Survey and performance evaluation of multiple access schemes for next-generation wireless communication systems," *IEEE Access*, vol. 9, p. 113428–113442, 2021. [Online]. Available: https://doi.org/10.1109/ACCESS.2021.3104509

[40] S. A. Yosef and L. F. Abdulameer, "Performance enhancement of vlc-noma employing beamforming function based vehicle-to-multivehicle communication system," *IETE J Res*, vol. 70, no. 7, pp. 6069–6080, 2023. [Online]. Available: https://doi.org/10.1080/03772063.2023.2290092

[41] S. Yosef and L. Abdulameer, "A systematic review on non-orthogonal multiple access (noma) based on visible light communication for intelligent transportation systems," *Tikrit Journal of Engineering Sciences*, vol. 31, no. 1, p. 278–290, 2024. [Online]. Available: https://doi.org/10.25130/tjes.31.1.23

[42] S. A. Yosef and L. F. Abdulameer, "Performance enhancement of vlc-noma employing beamforming function based vehicle-to-multivehicle communication system," *IETE J Res*, vol. 70, no. 7, pp. 6069–6080, 2023. [Online]. Available: https://doi.org/10.1080/03772063.2023.2290092

[43] Y. Saito, Y. Kishiyama, A. Benjebbour, T. Nakamura, A. Li, and K. Higuchi, "Non-orthogonal multiple access (noma) for cellular future radio access," *in 2013 IEEE 77th vehicular technology conference (VTC Spring), IEEE*, vol. 24, no. 4, p. 1–5, 2013. [Online]. Available: https://doi.org/10.1109/VTCSpring.2013.6692652

[44] G. Xu and Q. Zhang, "Mixed rf/fso deep space communication system under solar scintillation effect," *IEEE Transactions on Aerospace and Electronic Systems*, vol. 57, no. 5, p. 3237–3251, 2021. [Online]. Available: https://doi.org/10.1109/TAES.2021.3074130

[45] Z. Ding and H. V. Poor, "A simple design of irs-noma transmission," *IEEE Communications Letters*, vol. 24, no. 5, p. 1119–1123, 2020. [Online]. Available: https://doi.org/10.1109/LCOMM.2020.2974196

[46] X. Zhao and J. Sun, "Secure reconfigurable intelligent surface aided heterogeneous vlc–rf cooperative noma networks," *Opt Commun*, vol. 511, p. 127983, 2022. [Online]. Available: https://doi.org/10.1016/j.optcom.2022.127983

[47] H. Ma, H. Wang, H. Li, and Y. Feng, "Transmit power minimization for star-ris-empowered uplink noma system," *IEEE Wireless Communications Letters*, vol. 11, no. 11, p. 2430–2434, 2022. [Online]. Available: https://doi.org/10.1109/LWC.2022.3205703

[48] L. Rao, M. Pant, L. Malviya, A. Parmar, and S. V. Charhate, "5g beamforming techniques for the coverage of intended directions in modern wireless communication: in-depth review," *Int J Microw Wirel Technol*, vol. 13, no. 10, p. 1039–1062, 2021. [Online]. Available: https://doi.org/10.1017/S1759078720001622

[49] Q. Wu and R. Zhang, "Intelligent reflecting surface enhanced wireless network via joint active and passive beamforming," *IEEE Trans Wirel Commun*, vol. 18, no. 11, p. 5394–5409, 2019. [Online]. Available: https://doi.org/10.1109/TWC.2019.2936025

[50] X. Ma, S. Guo, H. Zhang, Y. Fang, and D. Yuan, "Joint beamforming and reflecting design in reconfigurable intelligent surface-aided multi-user communication systems," *IEEE Trans Wirel Commun*, vol. 20, no. 5, p. 3269–3283, 2021. [Online]. Available: https://doi.org/10.1109/TWC.2020.3048780

[51] A. Chaaban and M. Debbah, "Opportunistic beamforming using an intelligent reflecting surface without instantaneous csi," *IEEE Wireless Communications Letters*, vol. 10, no. 1, p. 146–150, 2020. [Online]. Available: https://doi.org/10.1109/LWC.2020.3023399

[52] J. Dang, Z. Zhang, and L. Wu, "Joint beamforming for intelligent reflecting surface aided wireless communication using statistical csi," *China Communications*, vol. 17, no. 8, p. 147–157, 2020. [Online]. Available: https://doi.org/10.23919/JCC.2020.08.012

[53] N. Tiwari and T. R. Rao, "A switched beam antenna array with butler matrix network using substrate integrated waveguide technology for 60 ghz communications," *nternational Journal of Electronics and Communications (ICACCI)*, vol. 70, no. 6, pp. 850–856, 2015. [Online]. Available: https://doi.org/10.1016/j.aeue.2016.03.014

[54] V. Venkateswaran and A. van der Veen, "Analog beamforming in mimo communications with phase shift networks and online channel estimation," *IEEE Transactions on Signal Processing*, vol. 58, no. 8, p. 4131–4143, 2010. [Online]. Available: https://doi.org/10.1109/TSP.2010.2048321

[55] H. Ajam, M. Najafi, V. Jamali, B. Schmauss, and R. Schober, "Modeling and design of irs-assisted multilink fso systems," *IEEE Transactions on Communications*, vol. 70, no. 5, p. 3333–3349, 2022. [Online]. Available: https://doi.org/10.1109/TCOMM.2022.3163767

[56] S.-P. Le, H.-N. Nguyen, N.-T. Nguyen, C. H. Van, A.-T. Le, and M. Voznak, "Physical layer security analysis of irs-based downlink and uplink noma networks," *EURASIP J Wireless Commun and Networking*, vol. 105, no. 2023, p. 105, 2023. [Online]. Available: https://doi.org/10.1186/s13638-023-02309-5

[57] D. Wang, M. Wu, Z. Wei, K. Yu, L. Min, and S. Mumtaz, "Uplink secrecy performance of ris-based rf/fso three-dimension heterogeneous networks," *IEEE Trans Wireless Commun*, vol. 23, no. 3, pp. 1798–1809, 2024. [Online]. Available: https://doi.org/10.1109/TWC.2023.3292073

[58] L. Shen, P. Wu, C. Ku, Y. Li, and Y. Chen, "D-star: Dual simultaneously transmitting and reflecting reconfigurable intelligent surfaces for joint uplink/downlink transmission," *IEEE Transactions on Communications*, vol. 72, no. 6, pp. 3305–3322, 2024. [Online]. Available: https://doi.org/10.1109/TCOMM.2024.3364988

[59] F. C. Okogbaa, T. Anjali, and F. A. F. S. A. R. Z. T. A. G. Kaddoum, Q. Z. Ahmed, "Design and application of intelligent reflecting surface (irs) for beyond 5g wireless networks: a review," *Sensors*, vol. 22, no. 7, p. 2436, 2022. [Online]. Available: https://doi.org/10.3390/s22072436

How to cite this article:
Batool R. Natiq, Lwaa Faisal Abdulameer. (2025). '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(2), pp. 155-162. `https://doi.org/10.30772/qjes.2024.151005.1272`