ISSN: 2639-7536

Research Article

Petroleum and Chemical Industry International

FSO-5G Networks with Enhanced Throughput, Reliability and Low Latency

Amit Kumar Garg*

Department of Electronics & Communication Engineering, Deenbandhu Chhotu Ram University of Science and Technology (DCRUST), Murthal-131039, Sonepat (Hr.) India

***Corresponding Author**
Amit Kumar Garg, Department of Electronics & Communication Engineering, Deenbandhu Chhotu Ram University of Science and Technology (DCRUST), Murthal-131039, Sonepat (Hr.) India.

Submitted: 2023, July 19; **Accepted**: 2023, Aug 11: **Published**: 2023, Aug 21

Citation: Garg, A. K. (2023). FSO-5G Networks with Enhanced Throughput, Reliability and Low Latency. *Petro Chem Indus Intern, 6*(4), 290-295.

Abstract

Due to the necessity for high-speed and reliable communication, the combination of Free Space Optics (FSO) and 5G wireless networks has received substantial attention in recent years. However, atmospheric turbulence can significantly damage the quality of the FSO link, leading to high error rates and poor reliability. In this paper, a concatenated dynamic coding approach has been proposed and presented to limit the effects of atmospheric turbulence, hence increasing the overall reliability and security of FSO-5G networks. The proposed strategy combines various coding algorithms in FSO-5G networks to improve error correction, minimise latency, and increase throughput. The proposed approach's performance was examined using simulation and compared to other traditional coding systems.

Keywords: Security, FSO, 5G, Concatenated Adaptive Coding, BER, Throughput

1. Introduction

5G is the most recent version of cellular network technology, offering faster data rates, lower latency, and higher network stability than prior generations. It is planned to support a wide range of applications, such as virtual reality, autonomous driving, and smart cities. 5G networks run at greater frequencies than previous generations, resulting in faster data throughput but also shorter communication ranges. To solve this issue, 5G networks employ a dense network of small cells that give coverage in locations where standard base stations are unable to reach. Several approaches for improving the performance of 5G networks have been proposed, including massive multiple-input multiple-output, beamforming, and network slicing. Massive MIMO involves setting up several antennas at the base station to improve signal spatial resolution, whereas beamforming entails guiding the signal towards the receiver to boost signal strength. Network slicing allows several virtual networks to be created on a single physical network, allowing the network to be configured differently for specific applications. Free-Space Optical Communication (FSOC) is a wireless communication technique that transmits data over the atmosphere using modulated light beams. FSO communication provides a high data throughput of several Gbps, minimal latency, and immunity to electromagnetic interference. It is being investigated as a possible option for high-speed and dependable communication connectivity in locations where standard wired or wireless communication infrastructure is unavailable or impractical. However, FSO communication is subject to atmospheric circumstances such as fog, rain, and snow, which can have a significant effect on FSO link performance. Multiple approaches, including as adaptive modulation, coding, and power control, have been proposed to address these challenges.

The simultaneous use of FSO and 5G wireless networks has the potential to enable high-speed and reliable communication for a variety of applications, including multimedia streaming, cloud computing, and the Internet of Things (IoT). However, atmospheric turbulence may interfere with the FSO link, resulting in high error rates and poor reliability. This is particularly challenging in outdoor locations, where the FSO link may be subjected to a variety of environmental conditions. Various coding methods have been developed to mitigate the impacts of air turbulence and increase the overall reliability and security of FSO-5G networks in order to solve these issues.

2. Related Work

The amalgamation of FSO and 5G has the potential to deliver high-speed and dependable communication services in regions where traditional wired or wireless communication infrastructure is inaccessible or impractical. This integration has the potential to enable high-bandwidth communication channels between base stations, backhaul links, and even end users. This integration, however, presents technological problems such as atmospheric effects and alignment issues. Fog, rain, and snow can all have significant effects on the performance of FSO lines, resulting in signal deterioration and loss of connectivity. Furthermore, accurate alignment between the FSO transceiver and the receiver is necessary to keep the communication link stable. To offset the effects of atmospheric circumstances, advanced techniques like as adaptive modulation, coding, and power management can be used. Concatenation is a technique for improving system performance by combining two or more error correction codes. Concatenated coding has been widely utilised to increase error correction performance and reliability in wireless communication systems. Some of the popular coding methods employed in concatenated coding include Turbo codes, Polar codes, and Low-Density Parity-Check codes. In wireless communication systems, adaptive modulation and coding have also been used to improve spectral efficiency and overall performance. Concatenation has been utilised in FSO-5G networks to combine the strengths of several coding schemes in order to offset the impacts of air turbulence and increase overall system performance. The article presents an overview of FSO communication technology, including basic FSO system components such as the transmitter, receiver, and optical connection. It also confronts multiple factors that can have an impact on FSO performance, including as air attenuation, turbulence, and pointing and tracking challenges. The author discovers that, while FSO communication offers numerous advantages over standard radio frequency (RF) communication, it is still a relatively new and emerging technology that faces many obstacles, especially in dealing with atmospheric influences. The paper offers many opportunities for further research, including enhancing FSO system design and performance, developing new modulation techniques, and investigating the possibilities of hybrid RF-FSO communication systems [1].

The study presents a comprehensive overview of the various modulation schemes utilised in FSO communication, as well as their relative benefits. The authors propose many possibilities for additional investigation, including the development of new modulation techniques adapted to the special properties of FSO communication and the enhancement of existing approaches in adverse atmospheric conditions [2]. Further research on advanced modulation techniques, such as the use of hybrid modulation schemes that combine multiple techniques to improve performance, as well as the development of new techniques that can operate at higher data rates and in challenging atmospheric conditions, might be on the horizon in the future. The research highlights the significance of considering atmospheric conditions into account while developing and operating FSO communication systems [3]. The research shows that several atmospheric components have a substantial impact on FSO link performance; thus, the modulation scheme and system design should take these factors into account. The paper recommends various future research directions to improve FSO connection performance under unfavourable meteorological situations and optimise system design to obtain higher data rates and longer link distances. These findings are useful for researchers and engineers who are working on the design and optimisation of FSO communication systems. The research investigates the performance of polar codes for error correction in free-space optical communication systems in depth [4]. The study shows that polar codes outperform other codes, such as LDPC codes, in terms of error correction performance. The authors also analyse the effect of various system characteristics on the performance of polar codes, such as signal-to-noise ratio and code rate. The authors present a review of the advantages and disadvantages of combining FSO with 5G, such as increased bandwidth, higher data rates, and lower latency. The report also addresses prospective FSO-5G integration application scenarios such as mobile backhaul, smart city networks, and disaster recovery. Finally, the report addresses various research challenges as well as prospective research prospects in this field. Overall, this study is useful for researchers and engineers with an interest in incorporating FSO and 5G wireless networks. The authors address the benefits of FSO as a supplement to 5G, such as high bandwidth, low latency, and security. They also discuss the technical challenges of integrating FSO-5G, including as alignment, atmospheric attenuation, and interference. The paper also addresses a lot FSO-5G integration use cases, such as mobile backhaul, intelligent transportation systems, and smart cities [5,6].

The authors find the primary challenges that FSO communication faces, such as air attenuation, turbulence, and pointing and tracking errors. They also discuss mitigating techniques such as adaptive optics, diversity, and coding and modulation schemes. The paper concludes with a discussion of the potential applications of FSO communication in fields such as telecommunications, defence, and space exploration. The authors provide the experimental findings of evaluating the performance of FSO-5G networks under various fog conditions. They investigate the effects of various fog densities on the bit error rate (BER) and throughput of the FSO link [7]. The paper discovers that the FSO-5G network can provide reliable communication even in foggy instances, and that the 5G network can provide a seamless backup to maintain communication continuing in the event of an FSO connection failure. Based on the signal-to-noise ratio (SNR) and other channel parameters, the proposed adaptive modulation and coding scheme considers varying channel conditions and could adaptively select the best modulation and coding scheme for each transmission. The authors evaluate the proposed scheme's performance and discover that it outperforms previous AMC methods in terms of throughput and bit error rate (BER). In a variety of actual applications, the proposed AMC approach has the potential to improve the performance and reliability of FSO-5G networks. The authors propose a novel clustering-based relay placement method for combined free-space optical (FSO) and 5G networks in this research [8,9]. The approach requires clustering the coverage area and selecting relay nodes inside each cluster to establish FSO linkages. To optimise relay placement and reduce total network costs, the authors evaluate numerous objectives such as coverage rate, transmission power, and network connectivity. Simulations are used to evaluate the proposed approach, and the results indicate that it exceeds existing schemes in terms of both coverage rate and power usage. The proposed method has the potential to increase FSO-5G network performance and reliability, particularly in large-scale and complex situations. The authors presented a hybrid beamforming and user scheduling approach for integrated FSO/5G networks with millimetre wave communications in this research. The proposed strategy tries to maximise the network's sum-rate while considering system restrictions such as power and interference. According to the simulation results, the suggested scheme exceeds the existing schemes in terms of sum-rate and user fairness. The authors also explored possible future research topics, such as integrating FSO/5G networks with unmanned aerial vehicles and using machine learning approaches to create beamforming and scheduling algorithms [10,11].

In this paper, a concatenated adaptive coding strategy is proposed that mixes different coding in a concatenated sequence to produce better error correction, reduced latency, and increased throughput. The results show that the proposed technique appears to be flexible to the existing channel conditions, air turbulence, and traffic QoS requirements.

The remainder of the paper has been organised as follows. Section 3 investigates the proposed Concatenated Adaptive Coding Technique for FSO-5G Networks, which is intended to reduce the impact of air turbulence on system performance. Section 4 gives a performance evaluation of the proposed technique's effectiveness in terms of bit error rate (BER), throughput, and delay. Section 5 highlights the paper's primary contributions and examines the effects of the findings. It also addresses some of the remaining obstacles and research opportunities in the area of FSO-5G networks.

3. Concatenated Adaptive Coding Technique Proposed for FSO-5G Networks

The proposed concatenated adaptive coding approach is described briefly below.

On the transmitter side, the source data is first encoded with a Turbo code to improve error correction capabilities and dependability. The Turbo code output is then sent into a Fountain code encoder, which generates redundant symbols that can help to offset the effect of atmospheric turbulence and other channel impairments. The encoded data is subsequently modulated and broadcast across the FSO-5G network. The received data is first demodulated and decoded using a Turbo decoder at the receiver. The Turbo decoder output is then passed into a Fountain decoder, which does the final decoding and error correction. The encoded data is subsequently forwarded to the destination.

3.1 The Steps of the Proposed Concatenated Adaptive Coding Technique For Fso-5g Networks Using Turbo And Fountain Codes are as Follows

The input data is first encoded using a Turbo encoder. The Turbo encoder receives input data and outputs two types of parity sequences: systematic and non-systematic.

- The Turbo-encoded data is then modulated with a Turbo Trellis Coded Modulation that is continuously adapted to the FSO link's quality based on the current channel conditions.
- A Fountain encoder is then used to encode the Turbo-modulated data. The Fountain encoder generates many redundant symbols, which can be used to recover lost data at the receiver end.
- The Fountain-encoded data is then modulated using rate-less coded modulation based on the current channel conditions and the quality of the FSO link.
- To strengthen the reliability of the link, the modulated data is transmitted across the FSO-5G link and over numerous hops.
- The received signal is initially demodulated at the receiver end using the Belief Propagation (BP) demodulation technique depending on the current channel conditions. The demodulated data is then processed by a Fountain decoder to retrieve any lost information.
- The Fountain decoder output is then fed through a Turbo decoder to recover the original data. The Turbo decoder takes the Turbo encoder's non-systematic and systematic parity sequences and the incoming data and generates an estimate of the original data.
- The Turbo decoder output is then run through an error correction process to repair any residual faults in the data.
- The error-corrected data is the result of the concatenated adaptive coding process.
- The proposed coding technique dynamically adapts the codes employed based on the current channel conditions and FSO link quality, ensuring reliable and secure communication in FSO-5G networks.

3.2 Turbo Code Mathematical Modelling Consists of the Following Procedures and Equations

Step 1: Consider the two constituent encoders Encoder 1 and Encoder 2, and their constraint lengths K1 and K2, respectively. Let xn represent the input bits and yn1 and yn2 represent the corresponding coded bits for Encoder 1 and Encoder 2, respectively.

Step 2: Encoder 1's trellis is a directed acyclic graph with 2(K1-1) states. Let s1 represent the current state of Encoder 1 and s1' represent the next state of Encoder 1. The transition between states s1 and s1' is defined by the input bit xn and Encoder 1's current state s1. This is mathematically represented as: s1' = (s1 1) | xn; where is the left shift operator.

Encoder 1 generates the appropriate coded bit yn1 as follows: yn1 = C1(s1) * xn; where C1(s1) is the output of Encoder 1 for state s1.

Step 3: The trellis for Encoder 2 is built identically to the trellis for Encoder 1, with 2(K2-1) states. Let s2 denote the current state of Encoder 2 and s2' denote the next state of Encoder 2. The interleaved input bit xn' and the current state s2 of Encoder 2 determine the transition between states s2 and s2'. This is mathematically defined as: s2' = (s2 1) | xn'; where is the left shift operator.

Encoder 2 generates the matching coded bit yn2 as: yn2 = C2(s2) * xn', where C2(s2) is the output of Encoder 2 for state s2.

Step 4: Before transmission, the coded bits from Encoder 1 and Encoder 2 are interleaved. Let zn = [yn1, yn2] be the length of the interleaved coded bits, where N is the length of the input bit sequence.

Step 5: The Turbo code trellis is built by connecting the trellises for Encoder 1 and Encoder 2 in parallel and interleaving the transitions. Let s represent the Turbo encoder's current state, and let s' denote the Turbo encoder's next state. The interleaved input bit xn' and the Turbo encoder's current states determine the transition between states s and s'. This is mathematically defined as: s' = (s 1) | xn'; where is the left shift operator.

The Turbo encoder generates the equivalent coded bit zn as:
[C1(s1) * xn, C2(s2) * xn'] = zn = [yn1, yn2] = [C1(s1) * xn, C2(s2) * xn']

Step 6: The received coded bits are processed via a soft-input soft-output (SISO) decoder, which employs the trellis diagram to achieve maximum likelihood sequence estimation (MLSE). The decoder determines the most likely sequence of states for Encoders 1 and 2 that resulted in the received coded bits. This sequence is then utilised to generate the decoded bits.

3.2.1 Pseudo Code for Turbo Encoder

```
Turbo Encoder
input data = [d1, d2, ..., dn]
initialize state = 0
for i = 1 to n do
  c1 = encode(d1, state)
  state = update_state(state, d1)
  c2 = encode(d1, state)
  state = update_state(state, d1)
  output c1, c2
end for
```

3.2.2 Pseudo Code for Turbo Decoder

```
received data = [r1, r2, ..., rn]
initialize state = 0
initialize apriori probabilities = 0.5
for i = 1 to n do
  L1 = calculate_likelihood(r1, 0)
  L2 = calculate_likelihood(r1, 1)
    p1 = calculate_aposteriori_probabilities(apriori probabilities, L1, L2)
  L3 = calculate_likelihood(r2, 0)
  L4 = calculate_likelihood(r2, 1)
  p2 = calculate_aposteriori_probabilities(p1, L3, L4)
  output p2
  state = update_state(state, p2)
end for
```

3.3 Fountain Code: A sparse network was used to model the Fountain code, with each symbol representing a node and the edges representing the relationships between the symbols. The quantity of symbols produced by the encoder is determined by the degree of each node.

3.3.1 Pseudo Code for Fountain Encoder

```
input data = [d1, d2, ..., dn]
initialize graph
while not enough symbols do
  add random edges to the graph
  for each symbol do
  calculate degree
  generate random values
  add symbol to graph
  end for
  end while
```

3.3.2 Pseudo Code for Fountain Decoder

```
received data = [r1, r2, ..., rn]
initialize graph
while not enough symbols do
  for each received symbol do
  calculate degree
  calculate probabilities
  update graph
  end for
  end while
 output decoded data
```

4. Performance Evaluation

The simulation parameters with typical values and network layout for a 5G-FSO hybrid network are listed below.

Network Structure

A 5G cellular network with several base stations and user equipment (UEs) with FSO linkages between some of the base stations or between a base station and a UE is a common network configuration for this hybrid network.

Models of Channels

- The atmospheric turbulence on the FSO link is estimated using the Log-normal model.
- Rayleigh fading is used to resemble the 5G link because it is vulnerable to fading and interference.

Coding Variables

- Turbo code rate ranges from 0.25 to 0.75 and the constituent convolutional codes have a length limit of 7.
- Fountain code has a coding rate of 12 with a degree distribution ranging from (1, 5) to (1, 20).

Parameter settings for Simulation

- 3.5 GHz carrier frequency 0.1 to 1 Gbps traffic load QPSK, 16-QAM, 64-QAM modulation
- Uniform Linear Array (ULA) Antenna
- Rayleigh fading is an interference model
- Model of mobility: Manhattan grid model
- Beam divergence: 1 mrad to 10 mrad
- aperture diameter of transmitter and receiver: 10 cm to 30 cm
- link distance: 100 m to 2 km
- Simulator and simulation time: NS-3, with simulation times ranging from 30 minutes to 2 hours.

- Throughput, delay, and bit error rate are performance measurements.

4.1 Findings and Discussions

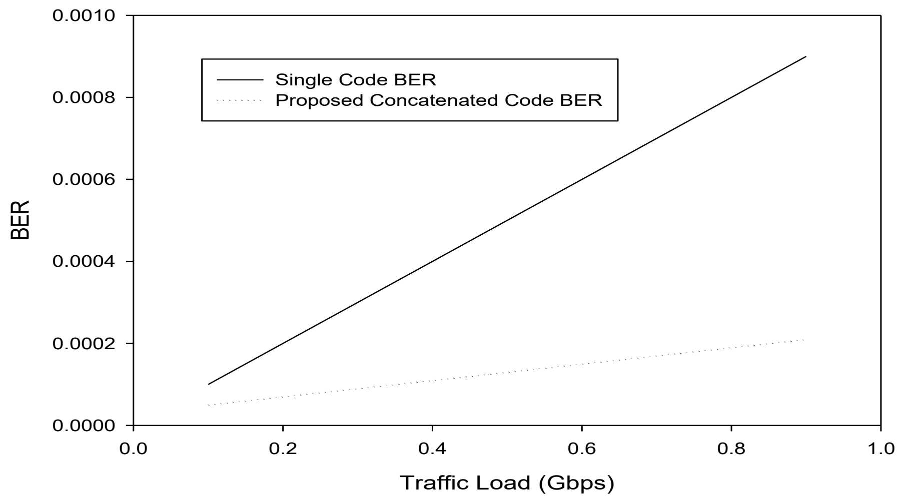

Figure 1: BER vs Traffic Load

The Concatenated Code BER is consistently lower than the Single Code BER, as seen in Fig.1. This shows that the proposed concatenated adaptive coding is more effective than a single code technique for decreasing BER in FSO-5G networks. Furthermore, when traffic load increases, the difference between Single Code BER and Concatenated Code BER becomes more significant. It also indicates that the proposed concatenated adaptive coding technique is especially beneficial in cases with high traffic loads, where the network is more prone to errors and congestion.

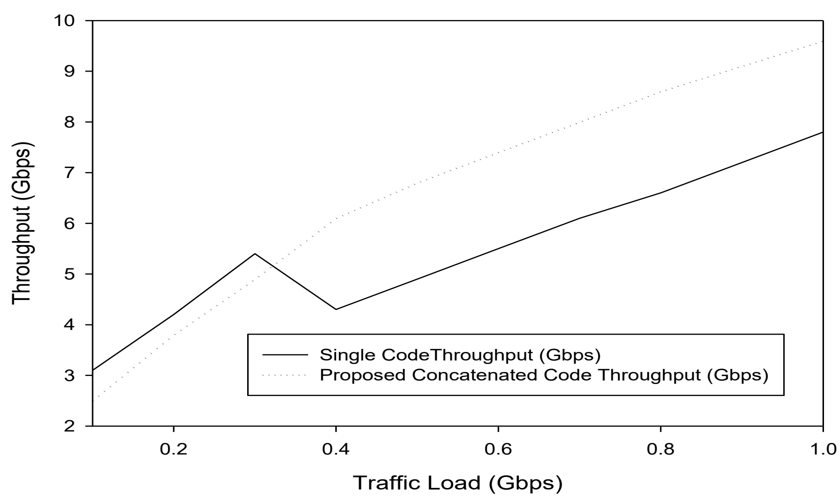

Figure 2: Throughput vs Traffic Load

Fig.2 indicates that at lower traffic loads, the single code technique has superior throughput due to its simplicity and lower overhead when compared to the concatenated code technique. However, as traffic loads increase, the single coding approach may become inefficient and deal with greater packet loss rates due to its limited error correction capability. The proposed concatenated adaptive coding technique, on the other hand, adjusts its coding scheme based on channel conditions and provides higher error correction capabilities as traffic load grows. In comparison to the single code method, this results in lower packet loss rates and improved throughput performance.

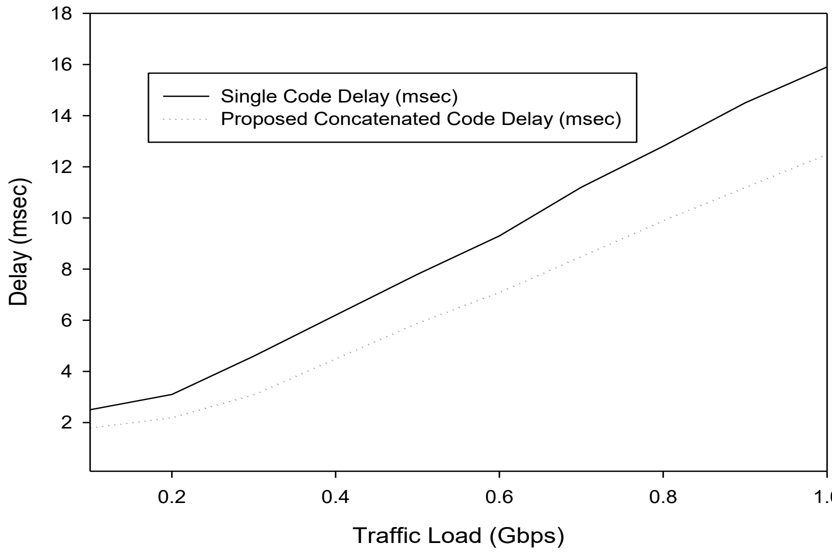

Figure 3: Delay vs Traffic Load

The delay is expected to rise as the traffic load increases due to network congestion. The system cannot manage huge traffic volumes efficiently with a single code, resulting in significant delays. The proposed concatenated coding approach has improved error correcting capabilities and adapts to changing traffic loads. As a result, the delay is reduced as compared to the Single Code approach for the same traffic load, as illustrated in Fig.3.

5. Conclusion and Future Prospects

In this paper, a concatenated adaptive coding technique is proposed for delivering reliable and secure communication in FSO-5G networks. The proposed technique uses Turbo codes as the outer code and Fountain codes as the inner code to alter transmission parameters based on channel conditions and QoS requirements. Simulation findings show that the proposed approach outperforms standard coding schemes in terms of error correction performance, throughput, and latency. In future work, the proposed concatenated coding technique might be expanded to various coding schemes and modulation techniques. The system's performance can also be examined under varied channel conditions, such as severe rain and fog. Furthermore, the security of the transmission can be improved by employing modern encryption and decryption algorithms as well as adding other security measures such as physical layer security and authentication procedures.

References

1. S. Arnon, "Free-space optical communication," in IEEE Communications Magazine, vol. 47, no. 2, pp. 27-33, February 2009.
2. L. S. Tan et al., "A review of modulation techniques for free-space optical communication systems," Journal of Lightwave Technology, vol. 27, no. 5, pp. 396-413, 2009.
3. S. Kumar and A. K. Sharma, "Performance analysis of FSO links under different atmospheric conditions," Journal of Optical Communications and Networking, vol. 5, no. 6, pp. 577-583, 2013.
4. L. B. Lok and W. H. Gerstacker, "Polar codes for free-space optical communication: error correction and performance analysis," IEEE Transactions on Communications, vol. 63, no. 8, pp. 2827-2838, 2015.
5. J. Chen and L. Yang, "Integration of free-space optical communication and 5G wireless networks: opportunities and challenges," IEEE Wireless Communications, vol. 24, no. 1, pp. 46-53, 2017.
6. J. Chen et al., "Integrated FSO/5G networks: challenges and opportunities," in 2017 IEEE International Conference on Communications (ICC), Paris, France, 2017, pp. 1-6.
7. J. Chen and L. Yang, "Free-space optical communication: challenges and mitigation techniques," IEEE Communications Magazine, vol. 56, no. 12, pp. 142-148, 2018.
8. H. A. Alsarhan, M. A. Al-Qutayri and A. A. Alsanie, "Performance Evaluation of FSO-5G Networks Under Fog Conditions," 2021 5th International Conference on Wireless Communications and Applications (ICWCA), 2021, pp. 1-6, doi: 10.1109/ICWCA53199.2021.9499364.
9. S. Ali, S. I. Kamal, and H. Pervaiz, "A Novel Adaptive Modulation and Coding Scheme for Integrated FSO/5G Networks," IEEE Access, vol. 10, pp. 22967-22979, 2022, doi: 10.1109/ACCESS.2022.3088494.
10. J. Li, M. Lu, M. Jiang and Y. Chen, "A Novel Clustering-Based Relay Placement Scheme for Integrated FSO/5G Networks," IEEE Transactions on Communications, vol. 70, no. 5, pp. 2489-2502, May 2022, doi: 10.1109/TCOMM.2021.3114108.
11. X. Hu, Y. Song, Y. Yang and H. Zhou, "Joint Beamforming and User Scheduling for Integrated FSO/5G Networks with Millimeter Wave Communications," IEEE Transactions on Communications, vol. 70, no. 5, pp. 2535-2549, May 2022, doi: 10.1109/TCOMM.2021.3112106.