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ANALYZING THE COMPREHENSIVE STUDY OF 5G HYBRID FREE SPACE OPTICS (FSO) COMMUNICATION NETWORKS FOR ENHANCED BACKHAUL CONNECTIVITY

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Abstract—**In the imminent era of fifth-generation (5G) and beyond, the utmost objectives revolve around increased capacity, accelerated data rates, reduced latency, and heightened service quality. Meeting these requirements necessitates significant improvements to cellular network designs. This extensive investigation highlights the crucial role of the architecture of 5G cellular networks, the widespread use of multiple-input multiple-output (MIMO) technology, and the incorporation of device-to-device communication in order to achieve these objectives. While free-space optics (FSO) emerges as a promising solution, its standalone application encounters challenges during unfavorable weather conditions. FSO systems are not affected by flying birds and trees as they rely on line-of-sight connectivity. Moreover, the performance of FSO is greatly affected by adverse weather conditions like fog and snow, resulting in considerable performance degradation. This study systematically examines ongoing projects in the same research domain, with a specific focus on hybrid FSO/radio frequency (RF) communication systems. Each technique employed in these models to achieve optimal performance in terms of data rate and Bit Error Rate (BER) for integration into 5G networks is thoroughly documented and analyzed.**

Keywords—**5G, MIMO, FSO, LOS Transmission.**

I.INTRODUCTION

Fifth the generation (5G) exchange is the next generation of mobile communication standards that could bring about revolutionary services with high system capacity, wide device connectivity, low latency, higher safety standards, low energy consumption, and very high service quality [7]. According to projections, 5G communication systems will enable highly populated heterogeneous networks, which will lead to 1000 times more mobile information storage per unit area and 100 times more connected wireless devices than there are on current systems. Future networks should therefore be able to accommodate high user data rates, low power consumption, and negligible end-to-end latency. Establishing high-capacity backhaul connectivity is essential to building hyper-dense superfast access networks for communications in 5G and beyond.

Radio wave (RF) is used in many different wireless applications nowadays. The Internet with Things, or IoT, paradigm cannot be supported and the rising need for 5G cellular bandwidth cannot be satisfied by the available RF spectrum. Current wireless technologies, which mostly employ frequencies below 10 GHz, have to deal with issues such spectrum usage restrictions, a small spectrum band, and strong interference from nearby RF access points. Scholars are investigating other spectrum, such millimeter and nanoscale waves, to get around these restrictions [8]. During the 2015 World Radio Conference, the International Telecommunication Union announced eleven further candidate areas for Foreign Mobile Telecommunication-2020 (5G communication), subject to stringent control by national and international agencies [15].

Due to the needs of cellphone data services, RF communication—which is essential to many applications—is seeing an increase in spectrum occupancy, which calls for the creation of rapid wireless networks. However, there are limitations to RF communication systems, including relatively low data speeds, insufficient security, and high-power consumption. Conversely, radio frequency (RF) communications are extremely successful even in inclement weather and do not involve clear visibility contact. Satellite Optical (FSO) communication and other optical spectrum options are gaining traction as viable substitutes for high-density, high-capacity networks in the future [6]. Compared to its RF-based equivalents, FSO-based network technologies have the benefit of offering high-data-rate services over a range of communication distances. FSO systems have transmission power restrictions and are prone to obstacle blocking, even though they are appropriate for both interior and outdoor applications [9].

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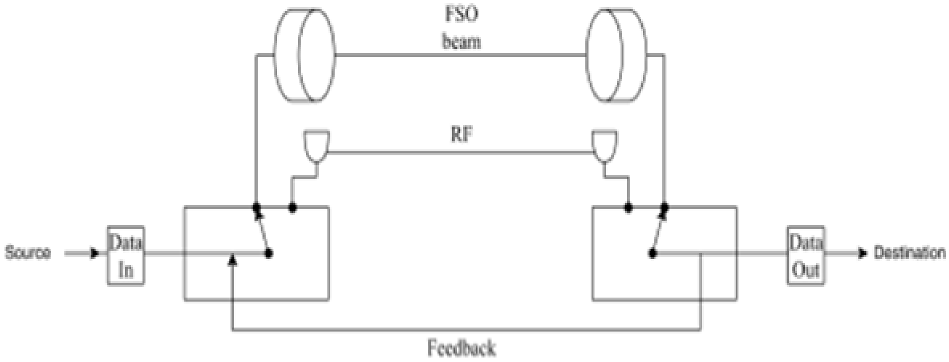

Fig. 1. Block diagram of FSO system [1]

Satellite Optical (FSO) communication and other optical spectrum options have begun to gain traction as viable options for high-density, high-capacity networks in the future [6]. In contrast to its RF-based analogs, FSO-based network technologies have the benefit of offering high-data-rate services over a range of communication distances. FSO systems have energy transfer limits and are at risk for obstacle blocking, yet they are appropriate for both interior and outdoor applications [9].Furthermore, the Free Ample room Optical (FSO) network of communications addresses the critical issue of last mile access, which has piqued the interest of researchers. The final networking segment connecting end users to online resources is referred to as the "last mile." The last mile problem, which occurs when all network traffic is routed through this connection, causes a delay in network throughput, is a common occurrence for this specific segment. Consequently, this connection's available bandwidth places limitations on the volume of data that can be sent to the relevant ISP [11].

Table1. Unique features of RF and earth-based links [1]

		FSO Links	RF Links
1.	data rate	Above 100 mb-gb(ps)	Less than 100 Mbps
2.	Ch.prevention	Up	Down
3.	Eqipparameter	Minute	Big
4.	Comn. Arch.	Measured	Non-measured
5.	Rangings	low	High
6.	Ascendancy	free	Non LOS

Most before attempts at classifying have focused mostly on the evaluation and distinction of Unrestricted Opto (FSO) systems, sometimes disregarding the creation of new or potential FSO linkages. As such, it is difficult, if not unattainable to integrate new and rising configuration classes into single-level classification schemes that are already in place. Many survey studies are forced to include more groups, leading to in inconsistent overall categorization methods and a dearth of systematic growth. Consider the pseudo (multi-spot) dilute system, which has been laid out as a separate class even though it shares certain features with diffuse systems. In addition, new developments in FSO technology have led to differences and even conflicts between various classifications and definitions, mainly when it comes to norms for naming and operational principles [17].

Systems incorporating the technology known as Free Space Opto (FSO) seem to be the best option for improving the performance of already-existing projects. A a complete duplex FSO system may reach an astounding 10 Gbps data rate. Furthermore, as Section 3 explains, FSO systems for communication outperform current systems in a variety of last-mile access applications. In order to get the best possible performance levels, this paper performs a thorough investigation of hybrid FSO networks, an area that has observed a rise in use recently [18]. The layout of the article is as follows: Section 3 evaluates FSO performance to alternative communication techniques for 5G backhauling, whereas Section 2 covers the conditions needed and fundamental concepts. Section 4 explores the multiplexing strategy, Section 5 talks about relay-based communication networks, and Section 6 gives a summary of several hybrid FSO systems. After that, Section 7 examines projects that only use FSO links, and Section 8 goes into great detail about models for communication systems that are fourth-, fifth-, and sixth-generation (4G), correspondingly.

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II.NEEDS AND STUDY

We investigate the basics and crucial theories of optical wireless communication in this part. Considering the many names for optical wireless technology that have been found in the literature, special attention is devoted to addressing the style of naming of this technology [1]. We also discuss the foundations and vital components of a common cosmic Optics (FSO) unity, such as modulation techniques, light sources, and photo detectors. It should be noted that neither the exact components used in optical networks nor the most recent advancements in their study are covered in great detail in this book. Relevant articles and publications are easily accessible for readers who wish to delve more into the principles of procedure, variances, and improvements in different kinds of luminescent devices and photo detectors.

2.1. Nomenclature

Originally known as fiber-less optics, ocular wlan and fiber-optic technologies for communication use the same electromagnetic spectrum band and have similar transmission bandwidth capabilities. Other names for this technology appeared in the literature as it developed and found uses in different fields, such as Lasercom, Optical Wireless Computing (OWC), and Free Space Opto (FSO). The designations "OWC" and "FSO" are gaining popularity in recent decades, making "fiber-less optoelectronic" and "lasercom" outdated [22].

To signify fiber-less optical technology, Kaushal and Kaddoum recently classified and surveyed it using the sign FSO. The two primary categories into which the authors split FSO technology are interior and outdoor systems, which are further separated into Geological Links and Interstellar Links. FSO, which stands for outside links, may be used in the vacuum of space and the atmosphere since it uses an unguided route in both situations. This also applies to environments where fiber-less optical infrastructures use unguided channels, such as indoor and underwater situations. Interestingly, it has been noted that FSO is sometimes referred to as aquatic OWC in aquatic situations [17].

2.2. Luminescent Provider

In spite of their large wavelength outputs and wide modulation bandwidths, Laser Diodes are semiconductor (LDs) and LEDs, or light-emit are the most common sources of illumination in space-based Free Space Opto (FSO) systems. LDs follow guidelines and power limits to reduce possible risks to skin and eye health, and are especially preferred for applications requiring high data rates [2].

The capacity of LDs to create coherent light, in which each individual light wave is correctly aligned and moves in the identical way at the same time, is one of its main advantages. When compared to LED lights, laser light can travel longer distances with less interference thanks to its coherent feature, which also allows it to be synchronized and directed forward. This results in better data rates

Nevertheless, LDs have some restrictions. Only point-to-point links may be used for communication due to their limited aperture. Though the idea of LD-based contact with the FSO has been around for a while, there are obstacles to the general use of LDs because of things like severe health hazards, financial concerns, and color mixing complications. Infrared light-wavelength diodes (LDs) have proven high-data-rate links for mobile access in spite of these obstacles.

2.3. Photo detector

Through the release and acceleration of current-conducting carriers inside the semiconductor material, a photo detector functions as a device made up of semiconductors that transforms the energy contained in photons of light towards an electrical signal [6]. The Avalanche Photodiode (APD) and the Positive-Intrinsic-Negative optoelectronic (PIN) are two of the most widely used photodiodes. These types are preferred because of their ubiquitous access in commercial-off-the-shelf (COTS) components, excellent quantum efficiency, and semiconductor architecture.

Amplifiers may be included into FSO receivers to provide a number of benefits, such as:

- Increasing the visible light signal strength with the use of an ocular mixer to counteract attenuation brought on by varying air conditions and successfully raise receiver sensitivity.
- Overcoming transmitted laser power eye-limit constraints.
- Mitiging the limiting impact of thermal noise produced in the receiver's electrical amplifier.

2.4. Modulation

The modulation methodology used, which is based on the particular application, affects the efficacy of optical communications, particularly transport validity, energy usage, and spectrum efficiency. For instance, Free Space Opto (FSO) systems frequently use Toggled Keying (OOK) modulation, which is recognized for its simplicity [14]. OOK, however, could fail to function well in more complex systems that need large data rates, such deep space communication. For such high-data-rate applications, Pulse Position Pwm (PPM) or one of its variants, such as Variable-PPM, is often picked.

There are two types of optical communication systems: coherent and non-coherent. Systems for non-coherent optical transmission are devoid of coherent local oscillator light; on the contrary, it employs differential phase and amplitude modulations.On the other hand, phasing and split amplitude modulations are used in synchronized optical transmission systems for coherence detection. Single-carrier pulsed modulation schemes, such as OOK and PPM, lose efficiency as data rates rise because of increased inter-symbol interference [17]. Time-domain equalization is also necessary

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for PPM, which presents difficulties in FSO lines with strong channel peculiarities and impairments.

Subcarrier Intensity Modulation (SIM), Multiple SIM (MSIM), and (OFDM) are utilized in these kinds of situations. With SIM-based methods, an optical source is driven by an RF signal that has been pre-modulated and contains the data. The Laser Melanoma Diode's input must stay non-negative; thus, a Direct Relevant (DC) bias is added to the pulse before driving the beam source in order to preserve a totally positive amplitude.

III.5G BACKHAULING N/W

FSO (Free Space Optical) technology finds applications in various scenarios, including:

1. Last-Mile Access: FSO can be deployed for last-mile access in areas where it is not feasible to lay fiber optic cables. This is particularly useful in remote or difficult-to-reach locations.
2. Backup Links: FSO systems can act as backup links for fiber networks. When the primary fiber network experiences failure or downtime, FSO can provide an alternative and quickly deployable communication solution.
3. Extending and Enlarging Fiber Networks: FSO can be used to extend or enlarge existing fiber networks. It can quickly bridge communication gaps and provide additional coverage.
4. Connecting Antenna Towers: FSO systems are capable of transferring data between antenna towers and the public switched telephone network at high data rates. This is essential for efficient and high-speed communication in the telecommunications industry.
5. Wide Area Network Access: FSO can bridge wide area network access, offering high-speed data transmission to end-users and serving as a backbone for trunking networks with high-speed requirements.
6. Point-to-Point (P2P) Links: FSO technology can connect two buildings or locations through point-to-point links, enabling high-speed data transfer between them.
7. Point-to-Multipoint (P2MP) Links: FSO can also be used for point-to-multipoint links, such as connecting satellites to the ground, expanding the reach of satellite communications.
8. Military Applications: FSO is a secure communication system that can be rapidly deployed in military applications, connecting large areas with minimal planning and setup time.

FSO systems offer several advantages:

1. High Transmission Speed: FSO systems provide high data transmission speeds, making them suitable for applications requiring rapid data transfer.
2. Quick Installation: FSO systems can be set up in less than 30 minutes, making them ideal for rapid deployment in various scenarios.
3. Low Initial Investment: They have a lower initial investment cost compared to some other communication technologies, which can be cost-effective for certain applications.
4. No Spectrum License Required: Unlike radio and microwave systems, FSO systems do not require a spectrum license for operation.
5. High Security: FSO systems are inherently secure, and they do not require additional security upgrades, making them suitable for confidential data transmission.
6. Low Error Rate: FSO systems maintain a low error rate even with high data rates, similar to optical fiber communication.
7. Spatial Reuse: They are immune to radio frequency interference, allowing for significant spatial reuse in densely populated areas.
8. Low Power Usage: FSO systems are energy-efficient and have low power consumption.
9. High Bandwidth: They offer high bandwidth, making them suitable for applications with demanding data requirements.
10. Speed of Light Transmission: FSO systems transmit data at the speed of light, ensuring minimal latency.

In summary, FSO technology is versatile and well-suited for various communication scenarios, offering high-speed, secure, and rapidly deployable solutions with low maintenance requirements.

Table 2. Provides a comparison between FSO and other systems

	Parameters	FSO	Optical Fiber	Microwave Radio	Coaxial Cable
1.	Fixing	Easy	Hard	Problematic	Simple
2.	Speed	High	Free	High	Medium
3.	Secrecy	High	More than High	Weak	Medium
4.	Prices	Down	Up	Up	Medium
5.	Recovery	Small	Small	Small	Medium
6.	Bandwidth	Problematic	Maximum	Medium	Up
7.	Spectrum legal	No Need	Not Need	Must	Must

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IV. MULTIPLEXING

The constant improvement of cell phone networks has highlighted the need for a reliable system that can provide customers with higher data transfer speeds and more channel capacity. Multiple Contributions Multiple Outcome (MIMO) systems leverage geographical diversity and geographical multiplexing methods to meet this need by using several antennas on both of the receiver's sides [1]–[5]. MIMO is a workable way to ensure that the receiver receives multiple identical copies of the broadcast data, hence reducing data loss due to fading and faults in the channel. This results in minimal power per bit and excellent spectrum efficiency, as well as improved system performance and dependability.

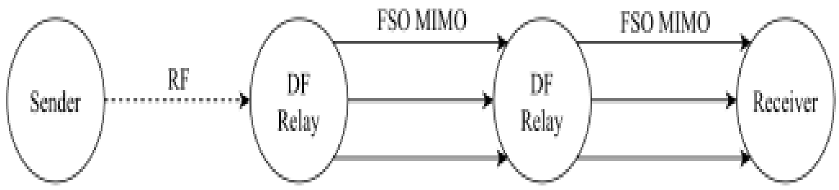

Fig. 2. Hybrid DF multi-hop RF/MIMO FSO [5]

This research aims to investigate and distinguish between the capabilities of several communication models, including Single-Input Single-Output (SISO), Single-Input Multiple-Output (SIMO), Multiple-Input Single-Output (MISO), and Multiplexing applications. Although all of these models are included in the research, the MIMO system is the focus of most attention because of its higher data transmission speeds and increased capacity. These characteristics make MIMO systems especially suitable for modern communication technology.

Table 3.summarizes the main differences between these communication models, highlighting the advantages of MIMO in terms of capacity and data transfer rates.

		SISO	SIMO	MISO	MIMO
1.	Expand	Single-Input Single-Output	Single-Input Multiple-Output	Multiple-Input Single-Output	Multiple-Input Multiple-Output
2.	Transmitter	1	1	More than 1	More than 1
3.	Receiver	1	More than 1	1	More than 1
4.	Channel Capacity	Down	Good by SISO	Good by SIMO	Up

Various approaches have been explored in the context of relay-assisted heterogeneous networks, including the use of Unmanned Aerial Vehicles (UAVs) equipped with buffers and other technologies [15] . These approaches aim to enhance communication reliability and performance. Here are the key findings without referencing numbers:

1. UAVs with Buffers: Moving UAVs with buffers have been employed to serve as relay nodes in heterogeneous networks, where both fixed and moving relay nodes coexist. This approach introduces mobility and storage capabilities to relay nodes, enhancing their versatility and potential for improving network performance.
2. SATN with Aerial Platform: In scenarios involving Satellite-Aerial Terrestrial Networks (SATN), aerial platforms operate as Amplify-and-Forward (AF) relays to facilitate communication between multiple users and a satellite. Users communicate with the relay using RF transmission, while the relay communicates with the satellite using a Free Space Optical (FSO) link. Beam forming (BF) techniques have been proposed to improve the signal quality and robustness of the network. These techniques aim to enhance the Signal-to-Interference-plus-Noise Ratio (SINR) for users and reduce outage probability, ultimately improving network performance.
3. Comparison of Distributions: Researchers have compared different probability distributions, such as the Malaga-M distribution and the gamma-gamma distribution, to assess their suitability for modeling FSO/RF hybrid systems under varying weather conditions [8]. The Malaga-M distribution is considered more advanced and comprehensive, particularly for scenarios with adaptive rate transmission and automatic repeat request. It performs well across different turbulence conditions. In contrast, the gamma-gamma distribution is suitable primarily for weak, moderate, and strong turbulence conditions.

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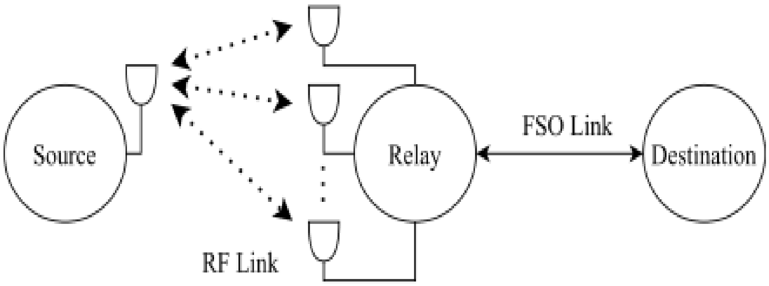

Fig. 3. Hybrid SIMO RF/ FSO [8]

These studies highlight the importance of selecting appropriate models and techniques to optimize the performance of relay-assisted networks and hybrid FSO/RF systems under different environmental and operational conditions.

V. HYBRID FSO NETWORKS

This section discusses various models that incorporate hybrid Free Space Optical (FSO) communication systems and address several associated challenges. Some of the key topics discussed include seamless mobility for mobile users and the coexistence of different communication technologies. Here is a summary of the key points without referencing numbers: -

1. Seamless Mobility in LiFi Networks: The section highlights the importance of achieving seamless mobility for mobile users in hybrid FSO communication systemsLiFi is a handheld wireless light-based communication technology that provides fast, two-way network access. This section introduces LiFi. Users are anticipated to travel within LiFi and WiFi networks as well as among LiFi cellular and wireless internet networks (vertical handover) inside a LiFi-WiFi network [19]. The paper cites Ayyash et al.'s research, which outlines the properties of diverse (LiFi + internet access) ecosystems and provides a framework for LiFi and WiFi cohabitation. RF macrocells, RF small cells, and optical small cells are all included in this network. It also investigates how base stations (BSs) in vast interior areas may be connected to one another via Accord-of-Sight (LOS) or Free Space Opto (FSO) links. This would enable connectivity for nodes that have LiFi receivers installed, which is in line with the Global Internet of Things (or IoT) idea.

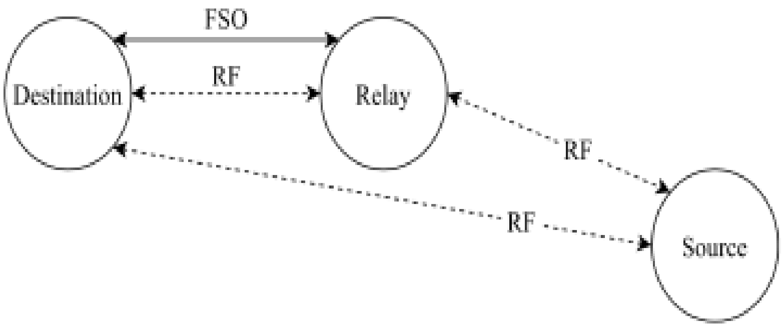

Fig. 4. RF/ FSO Comn. System [8]

2. The next section studies the use of long and short word codes in millimeter-wave (MMW) Fm and the use of Free Space Opto (FSO) communications, with or without Flexible Auto Repeat Request (HARQ) [7]. It also evaluates the performance of multi-hop and mesh networks. The FSO connection uses Hybrid Diversity (HD) methods by using a Decode-and-Forward (DF) link within the network, while the RF link follows MMW specifications. Performance evaluation takes into account many parameters including the variety of antennas and varied resonance times for both connections, and is done in terms of the likelihood of outages and ergodic attainable rates. The results show how many antennas are needed at the Fm/FSO hops in order for the RF route to achieve an identical transmission rate. It has been shown that HARQ improves dependability and energy efficiency.

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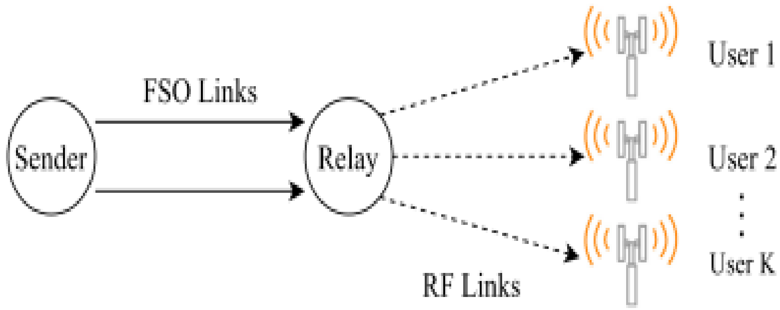

Fig. 5. Relay network of Dual-hop MMW multiuser mixed FSO-RF with opportunistic user scheduling [12]

3. Analysis of Hybrid RF/FSO Links: The examination of hybrid Electromagnetic Frequency/Free Space Opto (RF/FSO) connections, either with or without Hybrid Automatic Recurrent reQuest (HARQ), is further explored in this section. The research assumes that the destination has perfect Take on State Information (CSI) and develops formulas for the RF/FSO system's throughput, decoding probability, and outage probability under different conditions. We examine the effects of adaptive power utilization on throughput and chance of outages between the two lines. Additionally, the part compares the RF/FSO system's performance with individual RF and FSO connections and assesses its performance under various channel circumstances [4]. The signals are sent across parallel RF and FSO lines, where RF uses millimeter-wave (MMW) wavelengths in the carrier frequency range of 30 to 300 and FSO uses intensity modulation/direct detection (IM/DD).Data is sent to the recipient concurrently via RF and FSO channels. Although the FSO signal is transformed into a voltage signal at the receiver by a photodetector, the radio spectrum is down-converted into the baseband. The original signals are recovered with the use of decoding methods. It is shown that HARQ, flexible power utilization, and data variety improve the effectiveness and performance of the system, especially when it comes to retrieving lost data by referring to the other link. In their future work, the authors want to concentrate on transaction rate of errors analysis for FSO/RF networks utilizing finite-length codewords.

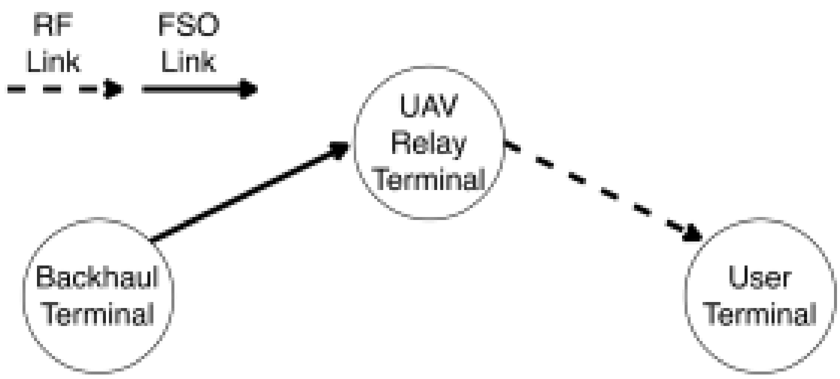

Fig**.** 6. UAV-assisted mobile relaying for dual-hop

These models and studies demonstrate the ongoing research and development in the field of hybrid FSO communication systems, addressing various challenges and exploring methods to improve system performance and efficiency.

VI. USING FSO LINKS ONLY

This section covers various studies and proposals related to Free Space Optical (FSO) communication systems and their performance in different conditions and under specific schemes. Here are the key findings without referencing numbers:

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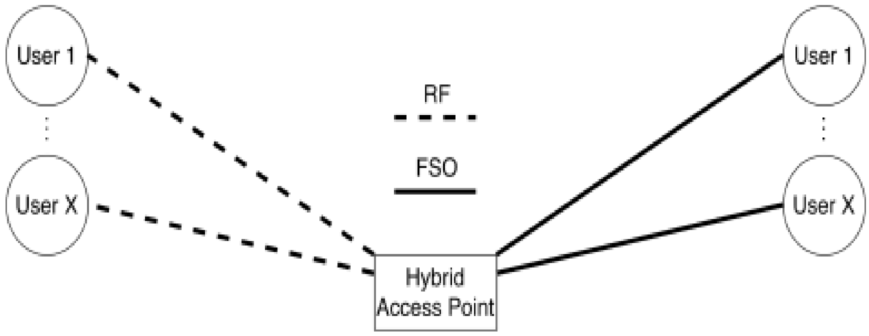

Fig. 7. Hybrid FSO/RF multiuser system model [15]

HARQ Scheme with BPPM: Kiasaleh investigates an FSO communication system that utilizes a Hybrid Automatic Repeat request (HARQ) scheme with Binary Pulse Position Modulation (BPPM) [1]. In this system, shot noise, ambient noise, and heat noise are all taken into consideration by the receiver as it uses a direct detection approach to determine the received signal. Given the packet error rate, the idea for Hybrid Automatic Perform ask for (HARQ) is evaluated. According to the results, the traditional Automatic Recurrent reQuest (ARQ)-FSO system is not as stable and reliable in the face of weather turbulence as the HARQ-FSO system. The effectiveness of HARQ is validated, particularly in moderate turbulence scenarios ($\sigma^2\_SC = 0.75$), exhibiting a notable increase when turbulence levels diminish [7].

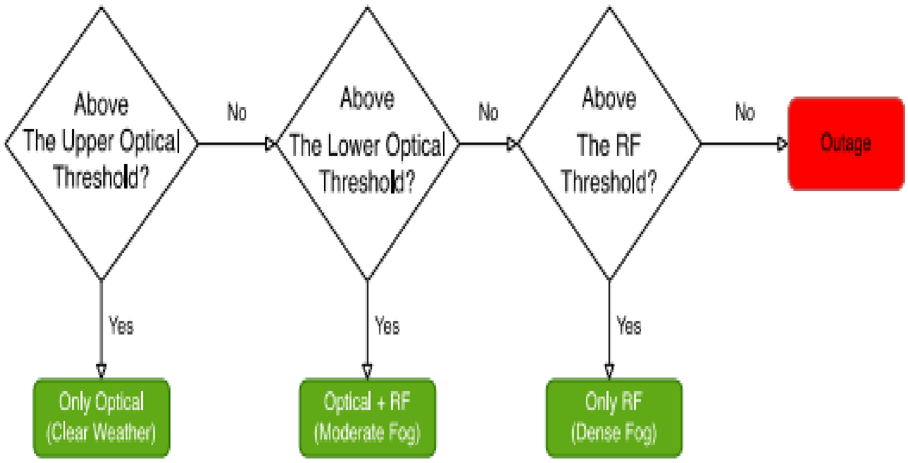

Fig. 8. Two optical thresholds and one RF threshold with switching scheme [20]

Hybrid Polaroid Division Muxing (PDM)/OFDM: Gurjit et al. propose a hybrid system that combines Polarization Division Multiplexing (PDM) and Orthogonal Frequency Division Multiplexing (OFDM) in FSO communication. To enhance transmission efficiency, this strategy transmits distinct signals using orthogonal states of polarization. Two polar orthogonal signals are separated from the optical signal; one is used for the carrier while the other is employed for encoded user data. To retrieve the original signals at the point of origin, both signals are separated and demodulated [20]. Testing of the system in a range of weather scenarios reveals that A lack of polar Division Multiplexing (PDM) improves spectral efficiency and user capacity. By reducing the amount of multipath and random fading effects related to Free Space Optics (FSO) transmission, OFDM (Orthogonal Frequency Division Multiplexing) enhances the overall quality and dependability of the system. On the other hand, when compared to clear weather, the reach of the FSO connection decreases under low-visibility situations because of increasing concentration and size of fog particles.

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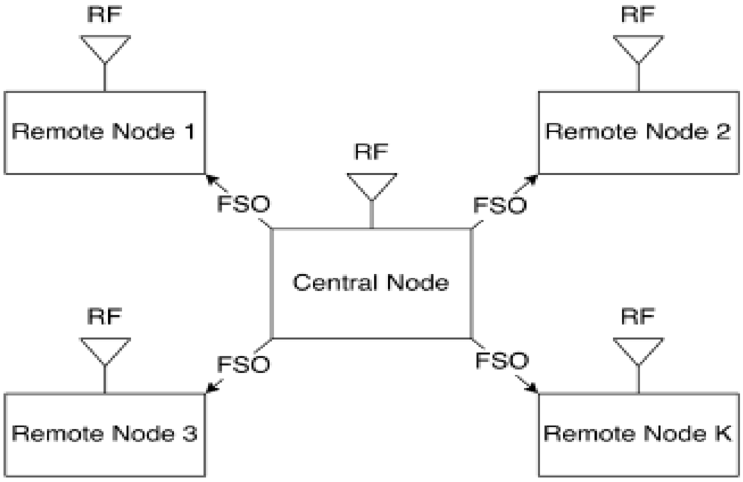

Fig. 9. Structure of a P2MP hybrid FSO/RF [11]

FSO Signal Transmission System Using PPM-GMSK Scheme: Sharma and Grewal suggest using the Pulse Position Modulation-Gaussian Least Shift pressing (PPM-GMSK) scheme in an FSO communication system operating under lognormal turbulence. Using Gauss-Hermite, the system's efficacy is assessed by way of Annual Bit Error Ratio (ABER) [13]. Studies show that each of the deviation ratio and energy use climb with the PPM modulation order. Although it uses more energy, 2-PPM-GMSK works better in this situation than 16-PPM-GMSK [17]. These research and recommendations advance our knowledge of FM networks and provide suggestions for enhancing their functionality in a range of scenarios and modulation and transmission means.

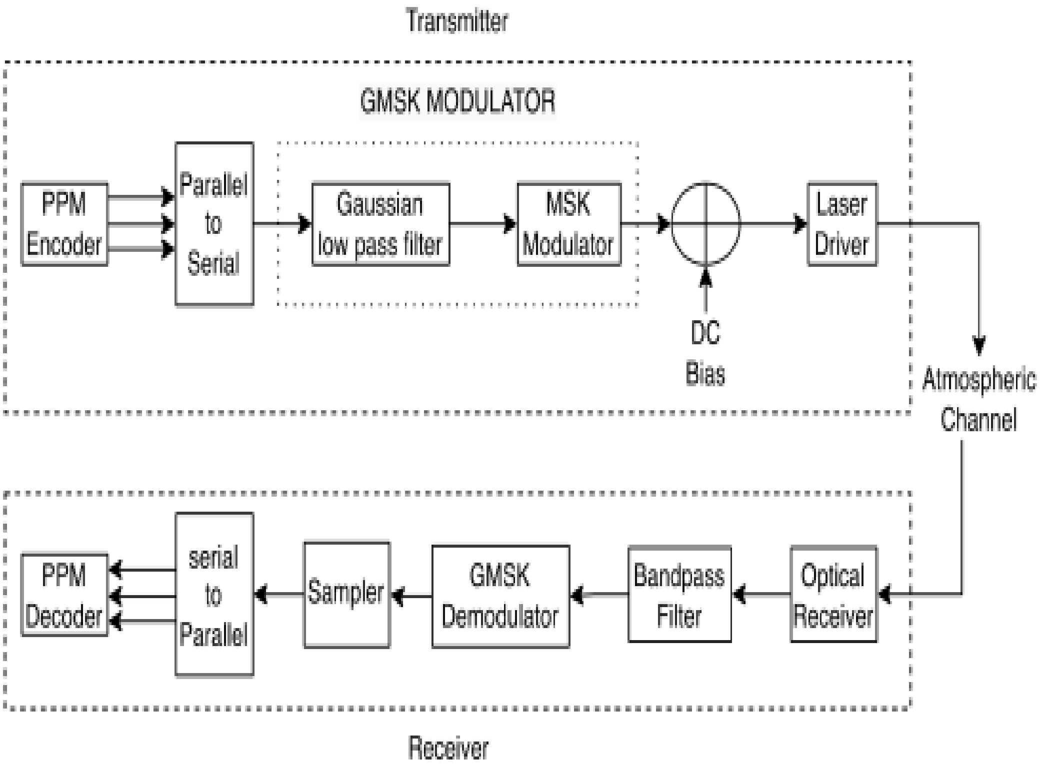

Fig. 10. Block diagram of hybrid PPM-GMSK[13]

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Table 4. Comparison of the different parameter techniques

REF.	FSO LINK DISTANCE (KM)	RF LINK DISTANCE (KM)	MAX DATA RATE	FADING DISTRIBUTION	FSO WAVELENGTH (NM)	RF FREQUENCY (GHZ)	SIMULATION SOFTWARE
[1]	8	Na	750 Mbps	GG	785	Na	Monte-Carlo
[2]	0.5	NDA	5 Byte/s/Hz	GG/Rayleigh	NDA	NDA	Matlab
[3]	NDA	NDA	7.23 Byte/s/Hz	GG/Rayleigh	1550	NDA	NDA
[4]	25	25	NDA	GG/Rician	NDA	NDA	Monte-Carlo
[5]	1	NDA	12 bit/s/Hz	M/Rayleigh	785	NDA	Monte-Carlo
[6]	NDA	NDA	NDA	GG/Rayleigh	NDA	NDA	Matlab
[7]	NDA	20	70 bit/s/Hz	GG/Nakagami-m	1550	1.9	Matlab
[8]	3	3	1.8 bit/s/Hz	GG/Nakagami-m	1550	60	Monte-Carlo
[9]	NDA	NDA	NDA	GG/Nakagami-m	1550	60	Monte-Carlo
[10]	NDA	NDA	9.2 bit/s/Hz	GG/Nakagami-m	NDA	NDA	NDA
[11]	NDA	NDA	NDA	GG/K	NDA	NDA	Monte-Carlo
[12]	NDA	NDA	0.5 bit/s/Hz	Malaga/AKM	NDA	NDA	Monte-Carlo
[13]	3.8	3.8	4.5 bit/s/Hz	GG/Nakagami-m	1550	60	Monte-Carlo
[14]	NDA	NDA	NDA	Malaga/Weibull	NDA	NDA	NDA
[15]	NDA	NDA	1.5 Gbps	GG/Rayleigh	NDA	NDA	NDA
[16]	0.5	0.001	40 Gbps	NDA	1550	100	NDA
[17]	NDA	NDA	55 Gbps	Log-normal/Rician	1550	10	NDA
[18]	NDA	NDA	20 bit/s/Hz	Malaga/Rician	NDA	28	Monte-Carlo
[19]	0.5	NDA	6 bit/s/Hz	GG/Rayleigh	NDA	NDA	Monte-Carlo
[20]	NDA	NDA	NDA	NDA	670	2.4	Matlab
[21]	NDA	0.005	NDA	GG/Nakagami-m	NDA	28 and 38	Monte-Carlo
[22]	600	600	900 Mb/s	GG/Nakagami-m	1550	2.4	Monte-Carlo
[23]	NDA	NDA	NDA	GG/Negative Exponential	NDA	NDA	Matlab

VII. CONCLUSIONS

In summary, the analysis of various projects and research in the field of Free Space Optical (FSO) communication systems has led to several key conclusions:

1. Hybrid FSO/RF Communication Systems: Hybrid systems that combine FSO and RF communication outperform standalone FSO or RF systems. They offer increased reliability and achieve full diversity by utilizing more than one link. In particular, parallel hybrid FSO/RF systems with independent paths to the receiver perform better than serial FSO-RF links, which require a relay to convert signals between FSO and RF [1]. The choice of relay type, such as Amplify and Forward (AF) or Decode and Forward (DF), impacts Bit Error Rate (BER) performance, with DF relays offering better performance at the cost of increased complexity.

2. Modulation Techniques: The choice of modulation techniques in FSO systems matters. External modulation, such as Return to Zero (RZ), is suitable for long-distance communication but can be complex and expensive. Non-Return to Zero (NRZ) modulation is more appropriate for short links, simpler, and cost-effective.
3. Advancements in Telecommunications: The rapid increase in internet traffic and multimedia users has put pressure on RF systems operating at modest data rates[15]. To meet the demands of high-speed and high-capacity communication, there is a need to transition from the RF domain to the optical domain. FSO communication provides the potential for extremely high bandwidth Line-of-Sight (LOS) wireless links between distant locations, making it a promising solution for modern communication needs.
4. Challenges in FSO Communication: FSO systems are obstacles with atmospheric phenomena such as air turbulence, scattering, and absorption. Multiple methods that first emerged for rf communication, like the variety of adaptive optics, correcting error codes, and modulation, work excellently to lessen the effect of external factors on FSO laser beams..
5. Hybrid RF/FSO Systems: The complementary nature of RF and FSO has led to the development of hybrid RF/FSO systems that offer carrier-class availability under diverse weather conditions. These systems represent a significant advancement in FSO communication technology.

6. Promising Future: The progress made in FSO communication suggests promising development prospects in the near term. Commercial FSO products for terrestrial and space applications are already available, and it is expected that FSO technology will play a crucial role in the global telecommunications revolution.

To summarize, the examination of Free Space Optical (FSO) communication systems reveals multiple significant discoveries. Hybrid FSO/RF systems exhibit superior performance compared to standalone FSO or RF systems, providing enhanced dependability and complete diversity [17]. While FSO systems encounter challenges from the atmosphere, various strategies for alleviation prove effective. The progress of hybrid RF/FSO systems represents a significant advancement in FSO technology, providing carrier-class availability in various weather conditions. With the unavailability of commercial FSO products and lack of technological advancements, FSO is unlikely to play a crucial role in the global telecommunications revolution.
The findings of these studies collectively highlight the potential of FSO communication systems and their ability to address the growing demands of the modern communication industry.

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