A Free Space Optic/Optical Wireless Communication: A Survey

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***Abstract*—The exponential demand for the next generation of services over free space optic and wireless optic communication is a necessity to approve new guidelines in this range. In this review article, we bring together an earlier study associated with these schemes to help us implement a multiple input/multiple output flexible platform for the next generation in an efficient manner. OWC/FSO is a complement clarification to radiofrequency technologies. Notably, they are providing various gains such as unrestricted authorizing, varied volume, essential safekeeping, and immunity to interference.**

Keywords*—*FS; OWC; attenuation; WDM; Radio-frequency

I. Introduction

The data is sent from one point to another using a communication system. Either the distance between them is only a few meters or thousands of kilometers. Data is routinely sent using an electromagnetic carrier wave with a frequency varying from a small number of megahertz to many hundreds of terahertz in the visible or near-infrared regions of the electromagnetic spectrum. Optical communication systems employ high carrier frequencies (~100THz) to distinguish them from microwave systems. It has a frequency carrier that is generally lower by five times of size (~1 GHz). They are often referred to as lightwave systems. Lightwave data transfer technologies that employ optical fibers are known as fiber-optic communication systems (FOCS). Since 1980, such systems have been implemented all across the world, transforming the telecommunications industry. Indeed, the introduction of the "information era" in the 1990s was aided by lightwave technology and microelectronics. Optical fibers have mostly supplanted copper wire communications in backbone networks in industrialized countries due to their benefits over electrical transportation. There is a significant need for transmission bandwidth, especially with the exponential rise in transmission bandwidth utilization (due to the rapid development of Internet data traffic) due to the following unique characteristics [1][2]. There is a lot of bandwidth due to the extremely high carrier frequency. There is very little loss, Compact and lightweight design, and extremely safe and unaffected by external electromagnetic interference. The best candidate for meeting this huge bandwidth need is fiber-optic communication [3].

Low latency, high reliability, scalability, and highly networked devices will be provided by fifth-generation wireless technology networks and beyond, which will enable the growing Internet-of-Things (IoT) applications and services [4][5]. The global adoption of complex multimedia apps, as well as the rising number of smart devices of all sorts, are all contributing to the enormous increase in mobile data traffic. OWC systems are thought to provide a compliment or alternative option to radiofrequency technologies due to rising demand on the restricted radio frequency "RF" spectrum. OWC is obtaining growing interest among the research community in several areas of application because of its major technical and operational benefits, and it is expected that OWC will revolutionize the communications sector now dominated by RF technology [4][6]. As shown in Fig. 1, research interests and activities in OWC, which cover the three main bands of ultraviolet, visible, and infrared, continue to grow, posing research and development challenges that must be addressed by the scientific community as a whole. Wireless communications have also advanced significantly in recent years in line with innovative tools. Portable devices and the E-society are all developing in attractiveness. OWC is a complementary solution to radiofrequency technologies, notably in the future 5G-based wireless communications network, and provides various benefits such as unrestricted licensing, huge Bandwidth, security, and non-interferences. However, the widespread use of "OWC" systems, infrared, and visual optical communications "VLC" systems face a number of challenges, including weather effects, safety regulations, lethal requests, complexity, and cost, necessitating ongoing research and development to address these and other related issues [4]. Fig. 2 shows the main structure for the FSO.

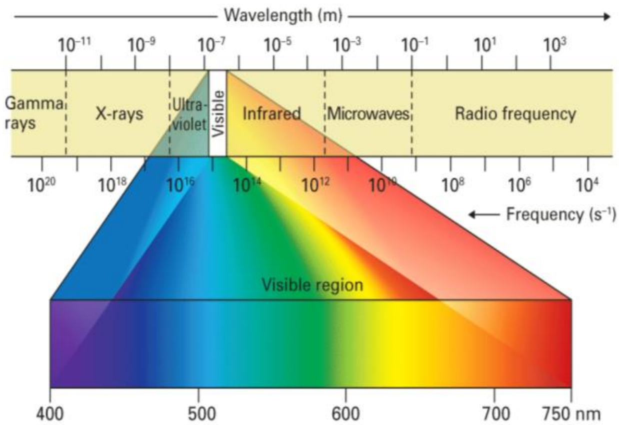

Fig. 1 The electromagnetic spectrum [4]

II. Contributions

This study contributes to the disciplines of optical networks and communications as follows:

A. To increase the bits rate.
B. To increase the number of users.
C. To improve the distance of the transmitter with changed atmospheric conditions.

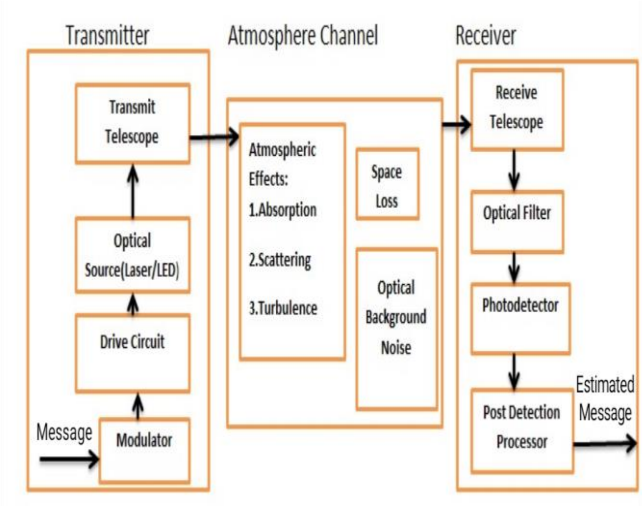

Fig. 2. shows the main structure for the FSO.

III. Aim of Work

We will be able to deploy our simulation without the need to create new fiber lines, thus developing the optical communication systems at reasonable and feasible costs.

IV. Methodology of the Work

To collect our data, will use the “OptiSystem package,” which is a Canadian license product key [7]. OptiSystem enables users to plan, test, and simulate (in both the time and frequency domain) in order to optical network design.

V. Literature Review

There are many researchers in previous studies who demonstrate the optical free wireless and free space optic with their all components, benefits, limitations, and applications, in the following subsequent, give many important of them:

Hybrid channels with type-11 schemes encompass parallel (FSO) and radio frequency (RF) connections in Perez-Ramirez et al. (2013). For various retransmissions, the method employed several equally augmented and RF bit-selecting forms. When compared to type-11, which employs an unsystematic selection bit for broadcast across the RF channel, it results in outcomes showing a gain of several dBs for the proposed style. The algorithm's performance is proven for various FSO and RF link circumstances [1].

A study to quantify the mean weak relationship between (FSO) and (RF) channels using investigational data obtained from a 1550nm FSO and 37GHz RF, global connections by Khatoon, Afsana, William G. Cowley et al. (2013). A bulking hidden Markov prototypical was used to simulate the combined figures of the RF-FSO stations under numerous weather settings. The simulation consequences displayed that the suggested simulator is accomplished exactly by duplicating the correlation fading mean and modeling the combined figures of hybrid FSO/RF channels under a range of meteorological conditions [2].

Hussein Saad Mohammed et al. (2013) planned an achievement (FSO) in a combination of the OCDMA\SAC\SCM scheme. To a drop the multiple-accesses interleaving and the overwhelming the overlapped frequencies. The study is completed affording to the Malaysian climate situations software. The study outcomes good data rates and minimum BER [3].

A heterogeneous situation in which RF/FSO equipment is organized is collected as a dual-hop communication scheme by Hossein Samimi et al. (2013). Rayleigh fading and M-distributed fading are used to represent the RF and FSO connections, respectively. They developed accurate closed-form equations for the output likelihood, demonstrating that current output data for mixed FSO systems may be produced, and the influence of pointing defects in the FSO connection is examined further [4].

Vishnevskii et al. (2013) presented a scientific prototype of a high-speed cross transmitting structure based on (FSO/RF) equipment. Using FSO-millimeters channel to convey combination data. Their study also resulted in ergodicity requirements for the Markov process that specifies the system's operation, as well as performance characteristics for the hybrid communication channel [5].

A hybrid Subcarrier Multiplying (SCM)-Spectral Amplitude Coding (SAC) Optical Coding Division Multiple Access (OCDMA) system based on Multi-Diagonal (MD) code using Free Space Optics suggested by Hussein Saad Mohammed et al. (2013). (FSO). The impacts of haze and rain attenuation have been considered while analyzing the suggested hybrid approach. According to the research, the hybrid system may be deployed in a mesh network. Furthermore, in storm rain and strong haze, this approach delivers a lower Bit-Error Rate (BER) [6].

For hybrid (FSO/RF) systems, Vuong Mai et al. (2014) presented the adaptive multi-rate (AMR) idea, which combines switching between two lines with the adapting rate on each connection. In the presence of atmospheric turbulence, frame-error rate, goodput, and outage probability in FSO and RF networks are investigated analytically. The suggested solutions outperformed traditional systems according to quantitative data [8].

Muneer Usman et al. (2014) suggested a hybrid (FSO-RF) system analysis. For the hybrid FSO/RF system, they introduced and analyzed a switching-based transmission mechanism. At any one moment, either the FSO or the RF link will be operational, with the FSO link having a greater priority. For FSO link functioning, they investigated together single-multi thresholding conditions. For the follow-on structure, the output data likelihood and BER have been developing [9].

A study of the OUTPUT possibility of (FSO\RF) scheme with easy exchanging was presented by Hossein Kazemi et al. (2014). Based on their availability, one or both links can be dynamic in the soft-switching technique. They constructed an expression in relation to dissimilar structure and weather form bounds using the proposed prototypical to show the outage performance in various weather situations, and numerical results are presented [10].

It Ee Lee et al. (2014) investigate the obtainability of ground (FSO) structures that are severely hampered by atmospheric channel fluctuations. The power detector device's quasi-linear output voltage characteristics are used as a valuable decision measure for implementing hard exchanging in a hybrid FSO/RF linking established on variations in visibilities. In command to permit effective exchanging among the FSO\RF links, the study's findings indicated that the suitable threshold voltage is firm by the target data rate and minimum BER [11].

By Tang et al. (2014), the network control techniques were developed for both nonfading and fading communication channels utilizing the physical interference model for the RF section of the network. They looked at how much throughput might be gained by adding FSO lines to the RF WMN. The results indicated that appropriately adding FSO lines may significantly boost the throughput of the original RF network [12].

Sushank Chaudhary et al. (2014) suggested Accompanying (FSO) enables a pervasive platform in order to reach underserved areas by modifying radio-subcarriers based on a carrier of optical. They went over the key characteristics of FSO in terms of ground and satellite structure. The results showed models of 1Gb/second transferring data over them [13].

Ehsan Soleimani-Nasab et al. (2015) investigated a combined RF/FSO system with aiming error and Nakagami-m fading in generalized gamma turbulence. Meijer-G&two-variable of FOX-H tasks provide a closing formula for output possibility and BER. They also included an examination of diversity gain. In comparison to symmetric interference, the results revealed that symmetric interference affects outage and bit error rate likelihood asymmetrically [14].

At the receiver, Kuldeep Kumaret et al. (2015) offered to quantize and encode relaying for assessing each bit using the log-likelihood ratio (LLR), and information was conveyed via high-speed FSO and hybrid FSO/RF lines. When optimal symbol mapping is applied, the study indicated that relaying with and without Forward error correction (FEC) coding enhances gain [15].

Tamer Rakia et al. (2015) used adaptive combining to investigate power adaption solutions for hybrid FSO/RF systems. They offered two techniques, one of which is based on the expected RF\. The outage probability expressions with and without adaptation are calculated, and the results revealed that the scheme with power edition accomplishes better findings performance [16].

Abir Touatiet et al. (2015) provided a case study on SO\RF structure in Qatar's severe climate. They used a soft switching technique using finite state Markov chains (FSMC) to describe channel fading and get the formula for outage probability. They also looked at how well the planned system performed in cloudy and bad weather. A gentle switching technique was implemented using an FPGA-based Raptor code interface, and the findings suggest that the proposed approach reduces the likelihood of a hybrid system going down [17].

In a dual-hop, Lei Kong et al. (2015) deduced the closed form precise and asymptotic moment generating function. They estimated M-array phase shift keying (PSK), differential PSK (DPSK), and no coherent's average symbol error rate (ASER). They also investigated ASER for K and Gamma-Gamma distributions, as well as ASER for high SNR [18].

Vuong V. MAI et al. (2015) suggested a hybrid FSO/RF system that uses the adaptive multi-rate (AMR) idea to transition between the system's two connections. Furthermore, a cross-layer design of AMR switching was provided utilizing an analytical framework based on the automated repetition request (ARQ) method and a Markov-chain prototypical for structure analysis employing framing error rate, excellent put, and connection exchanging across fading channels. The collected findings demonstrated that the suggested system outperforms the traditional one [19].

Marzieh Najafi et al. (2016) investigated efficiency maximizing in a parallel hybrid FSO/RF relay channel with numerous relays and nodes that are orthogonal to each other. They came up with the best relay selection and time allocation methods, and the suggested adaptive protocol outperforms the traditional one in terms of gain [20].

Multiple user varieties across parallel and hybrid FSO/RF were explored by Li Chen et al. (2016). With a link quality scheduling approach, a hybrid FSO/RF point-to-multipoint system was presented. Outage probability and average bit error rate were studied using an asymptotic closed-form formula [21].

Behrooz Makki et al. (2016) investigated the performance of hybrid FSO/RF lines with and without hybrid automated repeat requests, supposing channel start information (CSI) at the receiver (HARQ). The closure was constructed using the decoding probabilities, throughput, and outage probability expressions. In addition, the effect of adaptive power allocation on throughput and outage probability was assessed [22].

Users submit information over an RF connection via a relay node, which is then relayed to the destination via an RF/FSO link, according to a study by Vahid et al. (2016). For both delay partial and delay tolerant broadcast, fixed and adaptive link policies were devised. To investigate the throughput, they looked at combinations of link procedures. They recommended further study with different network topologies, such as many nodes parallel style [23].

A study of modulation format difficulties in Free Space Optical (FSO) Communications was presented by Ales Vanderka et al. in (2016). On the basis of a BPSK (Binary Phase Shift Keying) modulation approach, they worked with OOK (On-Off Keying) and SIM (Subcarrier Intensity Modulation). A simulation box with heat and wind sources was used to investigate the modulation patterns in air turbulence, according to the findings of the study [24].

Sooraj Parkash et al. (2016) clearly tested dense wavelength division multiplexing at a rate of 40 GB/s for 8 channels via an FSO connection structure. A 5GB/s transmit for each user. According to simulation results, the BER increased considerably when the data rate and distance were increased up to ten gigabit/second [25].

Saeede et al. (2016) presented a relay-based FSO system with orthogonal frequency division multiple access for backhaul purposes. They devised a resource distribution strategy to improve throughput in foggy situations as compared to a single FSO link. The study's findings were linked to the employment of a large number of relays, which might be halved [26].

On-off keying and the Gamma-Gamma distribution were utilized by Abir Touati et al. (2016) to calculate the influence of linked fading on the outage probability for varied intensities of turbulence and pointing errors using 16 QAM and Rician channel fading. According to the experiment results, pointing errors result in a considerable decline in link performance [27].

To minimize power usage, Yan Wu et al. (2017) investigated selecting links dynamically, power allocation, and dependability assurances for data transmission in a hybrid FSO/RF connection. A dynamic link selection and power allocation (DLSPA) method was designed using Lyapunov optimization and the concept of reliability queues. The findings revealed that power consumption might be lowered at the expense of consistent queue occupancy. Simulations were used to verify the analytical results [28].

Zhitong Huang et al. (2017) presented an evaluation of an FSO/VLC inhomogeneous connectivity for future ground\ocean design, particularly in (RF) or requiring secrecy circumstances. The transmission performance of the hybrid network described has been evaluated using an experimental platform. The findings supported the proposed hybrid optical wireless network's practicality [29].

Shubha Sharma et al. (2017) suggested a hybrid FSO/RF system with a transmitting aperture/antenna selecting (TAS) method that is a multiple-input single-output (MISO). The suggested scheme of (SNR): if SNR is more than the lower limit, the FSO's best connection is utilized, and if SNR is less than the lower limit, the RF subsystem's link is used. The findings calculated MISO and MISO hybrid FSO/RF outage probability and average symbol error rate (SER) [30].

Shubha et al. (2017) suggested a decode and forward (DF) relaying switching scheme in a dual-hop scenario, using Monte Carlo simulations to consider Nakagami-m and log-normal distributions for the cumulative distribution function (CDF), probability density function (PDF), and outage probability in closed. Compared to the extreme fading of RF connections, the current technology performs better than the various parameters of FSO links [31].

Kappala Vinod Kiran et al. (2017) developed and tested a hybrid FSO/RF system for communication between two computers under various channel circumstances with hard switching. For the RF communication link, the ISM frequency band was chosen, which can provide motivating outcomes for existing and future transmission systems [32].

U. A. Karai et al. (2017) conducted a study of the region of Hyderabad (Pakistan), where fog has a small influence, but rain causes considerable attenuation. Rain CCDFs were estimated at both of the connections. The results demonstrated that with basic OOK modulation and a link length of less than a few hundred meters, the necessary data rate of hundreds of Gbps might be obtained [33].

Tamer et al. (2017) investigated a point-to-multipoint (P2MP) network using a hybrid FSO/RF connection. They looked at parameters including achieved data from source to destination, transit of size buffer, latencies, lossing probability, and link usage to see how well the system worked. The results demonstrate that the P2MP hybrid FSO/RF system outperforms the standard PMP–FSO system [34].

M. Nasir Khan et al. (2018) created a throughput maximization algorithm (TMA) for an adaptive FSO-radio frequency (RF)communication system, which analyzes performance utilizing regular and right regular low-density parity check (LDPC) codes. When employing the correct standard LDPC coding, the TMA delivers a 2.25db greater gain in all-weather situations [35].

Banibrata et al. (2018) suggested a multimeter wavelength (MMW) radio frequency FSO link that could be utilized as a backup if the FSO connection was affected by severe meteorological circumstances. They calculated outage probability, mean bit error rate (BER), and capacity using mathematical expressions. In multipath transmission, the Single photon emission Gamma distribution is employed for irradiance variation, followed by Rayleigh fading [36].

Mohammad Ali Amirabadi et al. (2018) suggested a twin node of FSD/RF structure in which an access point linked users to the base station via the proposed system, demonstrating that the parallel combination of FSO and RF links, as well as the access point, increased capacity, reliability, and data rate. The Gamma distribution with pointing errors was used to explore the FSO link, while Rayleigh fading was used to investigate the RF link. Matlab simulation was used to construct and verify for bit error and output possibility [37].

Mohammad Ali Amirabadi et al. (2018) developed an FSO/RF method with movable users by an RF link while communicating with the base station via an FSO link. For fixed and adaptive gain relay methods, a closed-form formula for BER and outage probability was constructed and proven by simulations. The fixed gain system was a little complex, consumed more energy, and improved performance, according to the findings [38].

For the five-generation of wireless networks, Zeping Zhao et al. (2018) proposed a 200-Gb/s wavelength division multiplexing (WDM) transmission structure built around multiwavelength immediately modulated transmitters optic sub-assembly. To boost system capacity, the technique has been used in four-format pulse amplitude modulation, according to the test results. The approach is possible to use in an FSO transmission network for 5G wireless connections [39].

Light-fidelity (Li-Fi) is a wireless system that employs visible light as a method of communication instead of utilizing basic radio waves, as described by Lamia Ibrahim Al-Ibrahim et al. (2018) in their study. Data generated by Li-Fi is evaluated and processed so that intelligent decisions can be made to improve services in a variety of areas. The study's findings showed that a Li-Fi-based Internet of Things (IoT) architecture is feasible [40].

Wafa Muhammad-Reza Shaker (2018) proposed an option for a hybrid space-free (FSO)/radio frequency (RF) optical communication system that did not require the channel state in which the information was provided. The mean bit error rate and outage probability were given as closed expressions, even in the presence of significant turbulence. The results revealed an improvement in system performance by combining the complementing properties of FSO and RF channels [41].

A Comparison survey of (OWC) tools: Styles and uses were given by Mustafa Zaman Choudary et al. (2018). The goal of this study was to better understand the distinctions between optical wireless networks (OWC) and the existing radio frequency technologies [42].

Using the Opti-system software, Hossam Abd Elrazek Mohamed Ali et al. (2019) investigated the influence of environmental conditions such as rain, fog, haze, snow, and dust on the performance of optical wireless communications. In addition to functioning frequencies on atmosphere attenuation in various climatic circumstances of the free-space optical connection, the influence of vision is discussed. The findings demonstrated the ability to estimate the maximum distance between the transmitter and receiver, as well as analyze the optimum system performance [43].

Minghua Cao et al. (2019) investigated the impact of sand dust particles on laser signals. The small-angle approximation method was utilized in conjunction with the radiative diffusion method. Multiple scattering is prominent in air conditions with sandy dust, causing signal pulse delay and pulse broadening. According to a numerical simulation, and also the signal attenuation follows a negative exponential distribution of laser wavelength, and a laser with a longer wavelength provides better performance [44].

Ghassan Al-Nawaimi et al. (2019) proposed employing packet length optimization to increase data speeds for free-space optical (FSO) systems. At the receiver, the average ASNR was measured and relayed back to the transmitter. For the standard FSO with adaptive modulation and coding (AMC) and constant package length, the suggested technique provided a gain of (0.8-1.9 dB) [45].

The impact of dust on the effectiveness of FSO linking transport and amplitude modulating of a wave was investigated experimentally by Maged A. Esmail et al. (2019). The findings showed that poor visibility range has a substantial impact on the all-optical FSO connection, resulting in a high bit error rate (BER). Under the same dusty circumstances, an assessment of FSO\RF frequencies was conducted. The results demonstrated that the RF connection is unaffected by the dust storm, making it ideal as a backup for the FSO link in extreme dust circumstances [46].

Elyes Balti et al. (2019) introduced a dual-hop RF/FSO system based on amplifying and forwarding (AF) with fixed gain employing multiple relays. With partial relay selection, channel state information (CSI) was employed (PRS). The optical channel was exposed to double-Weibull fading, whereas the RF channel was subjected to Rayleigh fading. Heterodyne or intensity modulation and direct detection (IM/DD) techniques were utilized for the reception. The study results asymptotic outage probability (OP) for high SNR was shown to be closed-form, and the ergodic capacity was calculated using Monte-Carlo simulations [47].

Mazen Abdel-Latif et al. (2020) proposed employing a balancing center with a laser fog sensor to improve wireless optical connection performance (FSO). The system was simulated using MATLAB and OPTISYSTEM programming environments, MIE dispersion was used in the wireless optical connection, and a wavelength of 1550 nm for the transmitted signal. The study found in the situations of moderate, light, and very light fog, the quality factor increased from 3.6 percent to 44.45 percent [48].

Ibrahima Joy et al. (2020) conducted an investigation on the performance of collaborating transmission systems that employed combined error checking codes for the RF-FSO relay (disassembled and forward) QC-LDPC coding at the relay level. A gamma distribution was used to describe the FSO connection, and the White Gaussian noise (AWGN) model was used to simulate the frequency correlation. The results showed that the performance of the cooperating RF/FSO DF system based on QC-LDPC and SC-LDPC codes was better than that of RF/FSO systems without codes [49].

A study of technical aspects was given by Xudong Wang et al. (2020) to long-distance wireless power transfer systems, which are particularly beneficial for unmanned aerial vehicles, and technical indicators have been suggested and deployed to evaluate the performance of such systems both at home and overseas. The important parameters of the system's performance were gathered after a test was done using testing equipment. The results provided a good platform for long-distance wireless power transmission system performance evaluation studies [50].

Samir Ahmed AL-Gailani et al. (2020) gave a summary of existing improvements in FSO technology as well as the elements that will drive the technology's adoption worldwide. They presented fundamental principles across all sorts of FSO systems as part of the study, such as a system architecture composed of a single package and several beams. The analysis of the effects of rain and fog on the propagation of the FSO signal was focused upon in this study. The results demonstrated the FSO network's scalability using multi-packet hybrid FSO system applications, With the use of the WDM (Wavelength Division Multiplexing) technique [51].

Gebrehiwet Gebrekrstos Lema (2020) introduced an effort concentrating on reducing weather and geographic influences on FSO communication by decreasing the Bit Error (BER) Rate via optimization technique. The wireless optical communication system is capable of transmitting data at a rate of up to 10 Gbps. In terms of visible distance, Eye diagram, BER, and quality factor, the suggested wireless optical communication performance has been compared to the literature under various weather situations. The simulation results revealed that the suggested effort achieved better performance [52].

Abu Jahid et al. (2020) provided a review of a variety of outdoor and indoor FSO applications and services. Radio Over Free-space Optical (RoFSO) devices have been deployed. These systems are a great way to enable 5G and beyond while also reducing system constraints. The study's findings revealed that FSO technology has several advantages, including its premise, importance, demonstration, and current technological advancement. Opportunities for the near future were discussed, as well as potential problems that must be overcome to achieve the effective deployment of FSO plans [53].

Magdalena Garlinska et al. (2021) introduced an investigation of the impact of atmospheric situations on the strength of radiating recipients and the laboratories implementation platform for the FSO structure, which is an operation in the frame third of the atmosphere (8-12 m) under various weather conditions. In restricted eyesight, optical radiation with a wavelength of around 10 m has higher transmission qualities than near-infrared waves, according to analytical investigations and the findings obtained. This proves that FSO connections in the 8–12 m band are feasible [54].

Thiago R. Raddo et al. (2021) proposed tools for investigating the shift to the next cellular operators. These systems can manage large amounts of data and several users at once, making them a strong competitor for the next cellular operators. According to the findings, 5G and beyond Fronthaul technology can transfer signals with both broadband (up to 800MHz) and entirely centralized signal processing [55].

A simulation and examination of a 10×32 Gbit/s full-duplex optical WDM system were given by Sinan M. Abdulsatar et al. (2021). Multidisciplinary programming was used to introduce a hybrid communication system for external applications. A straining device established on (FBG) is incorporated into line with the fiber optic connection (FO-link) to track the system state. With 4-channels to do as standby or saving to the FO\link in the disaster occurs, the optical connection in free space has already been simulated, even when there is severe rain. The findings of the correlation revealed that the Q factor improved significantly when compared to the FO link [56].

A study on hybrid LiFi and WiFi networks (HLWNets) was performed by Xiping Wu et al. (2021). This hybrid network-integrated rising data transfer through LiFi with broad WiFi coverage. The study presented a survey-style introduction to HLWNets and an evaluation to show that HLWNets are superior to stand-alone networks. The findings revealed that the study was successful in situating the security layer of indoor and physical areas [57].

Under the dust effect, Mehtab Singh et al. (2021) suggested a unique design of radio over free-space optical (RoFSO) transceiver based on (MDM\OFDM). The (SNR) and power totally were used as major assessment criteria to study connection show and accessibility under the influence of a pure environment and several dust situations. The findings revealed a greater rating of data through an allowable SNR, as well as next-generation uses [58].

For uplink satellite communication using hybrid FSO/RF connections, R. Swaminathan et al. (2021) suggested single-hop and SAGIN-based dual-hop system models, and the performance was studied using analytical and simulation findings. The results demonstrated that owing to the backup RF link, hybrid FSO/RF systems outperform FSO systems in an uplink situation [59].

S. Song et al. (2021) presented a study to combine power regulation and link switching using Recurrent Neural Networks (RNN) to forecast RSSI to improve transmission effectiveness in hybrid FSO/RF systems. The suggested technique can properly estimate the trend of the Received Signal Strength Indication (RSSI), and the power control approach may successfully enhance the transmission quality of the FSO connection by lowering the frequency of switching, according to experimental results [60].

Malik Suman et al. (2021) presented research on an alternative implementation of IRS-assisted hybrid free space optics/radio frequency wireless communications using unmanned aerial vehicles (UAVs). They gave an asymptotic study of the system's average symbol error rate in a high SNR area, as well as a comparison of the diversity order and coding gain. Monte Carlo simulation is used to verify the produced results [61].

T. Kamalakis et al. (2021) looked at a method for connecting many battery-powered sensor nodes to a master node on the room's ceiling using low-cost infrared light emitting diodes to relay data. They demonstrated a thorough model for modeling the communications layer and energy consumption. The findings suggested that this strategy would be suitable for occasionally delivering low data rate signals carrying sensor information in enormous machine-type communication fifth-generation applications [62].

Moon Hyung-Joo et al. (2022) suggested a method for a radio-frequency (RF) lens antenna array improve coarse pointing performance in hybrid RF/FSO communications. When compared to traditional approaches, the suggested methodology employing a unique closed-form angle estimator reduces the lowest outage probability by over a thousand times [63].

G. D. Verma et al. (2022) suggested a mixed dual-hop free-space optical (FSO)-radio frequency (RF) communication system that serves the end user via a decode-and-forward (DF) relay that uses hybrid automated repeat request (H-ARQ) protocols on both hops to service the end user. According to the findings, the asymptotic analysis, which assists in the computation of the diversity gain, provided useful insights into the system performance. Monte Carlo simulation is used to validate the analytical results [64].

In the presence of various sorts of eavesdroppers, S. C. Tokgoz et al. (2022) explored hybrid FSO-mmWave systems from a physical-layer security standpoint. For FSO and mmWave communications, respectively, exponential atmospheric turbulence and Weibull fading channels are taken into account. They show that the analytical formulas match exactly with Monte-Carlo simulations based on the results [65].

For simultaneous high-speed and low-speed data transmission, S. R. Teli et al. (2022) developed a single-input and multiple-output (SIMO) hybrid VLC system employing PD-based and IS-based Rxs. They tested the proposed scheme's performance while taking into account interlink consequences. Results showed that at AOL of 0–0.2, the measured bit error rate for the PD-based VLC is below the forward error correction limit of 3.8103 for RbLow of 2.5 and 5 kb/s at RbHigh of 35 and 60 Mb/s, respectively, and 2) the reception success rates for the IS-based VLC link with the camera gain of 4 dB and RbHigh of up to 70 Mb/s are >96 and 90% at RbLow of 2.5 and 5 kb/s, respectively [66].

O. B. Yahia et al. (2022) presented a hybrid RF/FSO transmission technique for SatCom, in which the satellite chooses between RF and FSO connections based on weather conditions collected from sensors and utilized for context awareness. They used diverse weather conditions to construct outage probability (OP) expressions to measure the performance of the proposed network. In addition, asymptotic analysis is used to determine the diversity order.

The findings reveal that the suggested technique outperforms dual-mode traditional hybrid RF/FSO communication in terms of OP while also providing some power gain [67].

H. D. Le et al. (2022) proposed a thorough mathematical approach for evaluating TCP throughput under the combined impact of Internet congestion losses and transmission faults at the last-mile link from the satellite to the vehicle. To increase TCP throughput on satellite-to-UAV communications, the link-layer incremental redundancy hybrid automated repeat request (IR-HARQ) protocol was used. The numerical results revealed non-trivial findings and insights for TCP performance in satellite/FSO-based IoVs, in which the ideal UAV settings are determined to optimize TCP throughput [68].

Hoang D. Le et al. (2022) proposed a cross-layer architecture of error-control protocols with rate adaptation for free-space optical (FSO) burst transmission in satellite communication systems. They presented a sliding window method based on HARQ for high-data-rate and long-distance FSO-based satellite systems. The findings clearly proved the influence of air turbulence and aiming error on system performance and support the best parameter selection. Monte Carlo simulations were also run to verify the accuracy of theoretical derivations [69].

S. Zargari et al. (2022) presented a technique for the issue of maximizing the total amount throughput of K users in a hybrid heterogeneous visible light communication (VLC)/radio frequency (RF) wireless communication system by optimizing the transmission time intervals of a time division multiple access (TDMA) scheme allocated to the users. To investigate the trade-off between the UL and DL sum rates, they presented a multi-objective optimization problem (MOOP) technique. After that, the non-convex MOOP structure was translated into an equivalent form, resulting in a set of Pareto optimum resource allocation strategies. Numerical data were used to demonstrate the efficacy of the recommended strategies [70].

X. Wu et al. (2022) conducted a study on the quality of service (QoS) of wireless networks that combine light fidelity (LiFi) and wireless fidelity (WiFi) (WiFi). For hybrid LiFi and WiFi networks (HLWNets), QoS-driven load balancing is investigated in two scenarios: single-AP association (SA) and multi-AP association (MA) (MA). In each situation, a problem is stated to minimize the packet loss ratio and delay, and a low-complexity iterative method is presented to solve it. The findings revealed that innovative approaches, particularly MA, may efficiently balance traffic loads among APs and improve QoS performance [71].

M. Obeed et al. (2022) suggested a study that uses an iterative strategy to solve a mixed-integer non-convex optimization problem. The study was then optimized to maximize a network-wide weighted sum rate in order to jointly determine the strong-weak user pairs, the weak user's serving link (i.e., either direct VLC or hybrid VLC/RF), and the power of each user message, all while being constrained by user connectivity and transmit power. Simulations demonstrated that the proposed method outperforms the current non-orthogonal multiple access (NOMA) strategy in terms of VLC network performance (i.e., sum-rate and fairness) [72].

Basheer and Essa (2022) suggested a new flexible platform for the hybrid FSO/WOC-based MIMO network. Their results pointed to a good output power signal and opening eye BER for all channels [73].

VI. Conclusion

The exponential demand for the next generation of services over free space optic and wireless optic communication needs to adopt new policies in this area. In this review article, we bring together an earlier study associated with these schemes to help us implement a multiple input/multiple output flexible platform for the next generation in an efficient manner. OWC/FSO is a complement clarification to radiofrequency technologies. Notably, they are providing various gains such as unrestricted authorizing, varied volume, essential safekeeping, and immunity to interference. Finally, our suggestion for future works is to conduct studies on the effect of global warming and dense dust on the FSO links in Iraq's climate.

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