Optical and RF Hybrid Networks: Uniting Technologies for Enhanced Communication, Advantages, Challenges & Future Scope

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***Abstract* -- The radio frequency (RF) which is the counterpart of optical wireless communication (OWC) offers great benefits to the wireless communications. OWC technologies have proven to be capable of handling the increased traffic brought on by the Internet of Things' (IoT) widespread connectivity and the future 5th generation (5G) wire-free communication systems. Therefore, since OWC and RF have compatible features, integrating the two is regarded as a promising approach to enable 5G and many other future communication systems. Hybrid wireless systems that combine RF and optical technologies are a fantastic way to get beyond the limitations of single systems and keep the benefits of each. An optical/optical wireless hybrid system comprises of two or more types of OWC technologies, as opposed to an RF/optical wireless hybrid system, which incorporates RF and optical-based wireless technologies. The performance of individual wireless networks in terms of throughput, dependability, and energy economy can all be improved by co-deploying wireless systems. This paper is a comprehensive study on the subject, examining the current state of the art and major areas for future research in optical wireless hybrid networks. The literature on optical wireless hybrid networks, including RF/optical and optical/optical systems, is summarized technically in the section below. For various combinations of hybrid systems, such as technologies based on RF, such as Bluetooth, Li-Fi, macrocells, small cells, wireless fidelity, visible light, optical camera, & free-space optical communication. For hybrid acoustic/optical systems, we also consider underwater acoustic communication. The advantages of hybrid systems are described in depth. The key obstacles are listed that must be removed for optical wireless hybrid network systems for 5G and IoT paradigms to be successfully deployed.**

Keywords— RF, Optical Wireless Hybrid Networks, Wi-Fi, VLC, OCC, UWC, FSO, LOS

I. INTRODUCTION

A new category of communication networks called optical wireless hybrid networks (OWHNs) combines the benefits of wireless and optical fiber technology. OWHNs are an excellent choice for many applications, including video streaming, cloud computing, Internet of Things (IoT) devices, and smart cities [1], since they can offer high-speed and dependable connectivity, low latency, and low power consumption. The necessity for high-speed internet connectivity and the constraints of conventional wireless networks are what is driving the development of OWHNs. OWHNs use wireless technology for last-mile connectivity while optical fibers are used for long-distance data transmission. Utilizing optical wireless converters, these two networks are combined. To provide smooth communication between the optical and wireless networks, the optical wireless converter converts optical impulses [2] into wireless signals and vice versa.

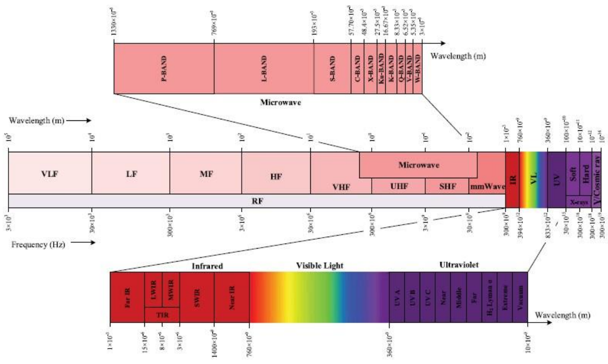

Fig. 1. Electromagnetic Spectrum

The benefits of optical and wireless communication technologies are combined in optical wireless hybrid networks (OWHNs), which offer a scalable and effective communication infrastructure. OWHNs can offer scalability, low latency, and high-speed connectivity, all of which are critical for contemporary communication systems. We give an overview of OWHNs in this paper, along with some of their benefits and drawbacks. The development of novel optical wireless converters, integration with 5G and Li-Fi [3] technologies, and the creation of new routing and switching algorithms are some of the current research directions in OWHNs that are covered in this article. We also go over the uses of OWHNs in a variety of industries, including video streaming, cloud computing, IoT devices, and smart cities. Finally, we discuss certain OWHNs' limitations and potential future applications. Hybrid wireless systems make it possible to combine two or more wireless technologies to improve functionality and get around individual technologies' drawbacks. While optical/optical wireless hybrid systems offer the convergence or integration of two or more different OWC systems, RF/optical wireless hybrid systems offer the convergence or integration of RF and OWC networks [4]. It can supply services regardless of the fixed or mobile network and offers seamless communication between fixed and wireless networks.

The rapid development of wireless communication technologies has increased the demand for high-speed, reliable, and secure data transmission. Optical wireless hybrid networks, a combination of optical and wireless communication technologies, have emerged as promising solutions to meet these requirements [5]. The constant growth in the number of multimedia applications generates a large amount of mobile data that calls for high-data-rate wireless access. Future 5G communications will provide a variety of new services with extremely high system capacity, large device connectivity, extremely low latency, extremely high security, extremely low energy consumption, and an incredibly high quality of experience (QoE). The upcoming 5G and beyond communication networks have a significant issue in supporting the tremendously high volume of data. As a result, the requirement for effective technical solutions to provide quality of service (QoS) for end users is expanding exponentially with the use of mobile data [6]. It is commonly known that radio frequency (RF) communications are getting more constrained due to the constrained spectrum resources in wireless networks.

As a result, many researchers currently view the license-free optical spectrum [1 mm–10 nm] as a possible complementary technology to RF to meet the expanding demand. Such a system is known as optical wireless communication (OWC), which uses an optical spectrum as the communication medium. OWC has emerged as a promising alternative because of the rapid advancement of light-emitting diodes (LEDs). In addition to offering high-quality communication features such as electromagnetic interference-free operation [7], high security, and high energy efficiency, OWC technology can utilize a large optical spectrum. At ordinary indoor illumination levels, data throughput of 100 Gbps is demonstrated using OWC. Some OWC technologies, such as visible light communication (VLC) and light fidelity (LiFi), utilize the existing lighting infrastructure to achieve wireless data transfer. With the increasing demand for high-speed data transmission, there is a need to explore new possibilities for data communication. Optical wireless hybrid networks have the potential to provide high-speed connectivity, improved reliability, and security. This paper aims to assess the feasibility of this technology and highlight its advantages and limitations.

The constraints of conventional wireless networks and the rising demand for high-speed internet connectivity served as the impetus for the development of OWHNs [8]. Traditional wireless networks might have their performance negatively impacted by interference and a small coverage area. A modern communication infrastructure that can deliver dependable and secure connectivity is also necessary given the growth of IoT devices and the rising need for high-speed internet connectivity. By offering high-speed, dependable, and secure connectivity, OWHNs can play a significant part in resolving these issues. In the context of the Internet of Things (IoT), where dependable and secure communication is essential, OWHNs can also facilitate the development of smart cities and IoT devices [9]. A scalable and effective communication infrastructure that can satisfy the needs of contemporary communication systems can be provided by the integration of optical and wireless communication technologies in OWHNs.

The paper discusses various problems with various wireless hybrid systems that make up the OWC networks. In this paper, several problems relating to various wireless hybrid communication technologies that make up OWC networks are covered. For the potential combinations of hybrid solutions, we consider various OWC technologies including VLC, OCC, LiFi, and FSO as well as RF technologies like femtocell, WiFi, macrocell, and microwave/millimetre-wave (mmWave) links.

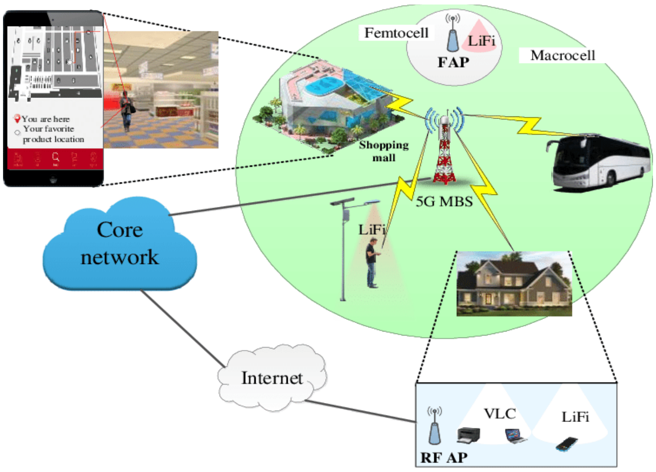

Fig. 2. Multi-Tier Networks with Optical Network

In a multi-tier architecture, the coverage of one or more additional networks is layered on top of the network coverage. With a 5G macrocellular base station (MBS), the coverage area is larger. The RF access point (AP), such as WiFi or a femtocell AP (FAP), generates a small tier inside a house. Three-tier networks are made possible by the availability of VLC or LiFi attocells, which adds a new layer. A two-tier network is also created by a LiFi employing a streetlight [10]. Users can utilize the OCC system inside a mall to find themselves as well as to find out information about products, forming a two-tier network. Users can connect to a macrocell, femtocell, or LiFi attocell network inside a bus, forming three-tier networks. The RF small cell known as a femtocell is used to increase cellular network coverage inside a specific geographic area. Attocell networks are cellular LiFi networks with cells that are smaller than a normal RF femtocell.

Load balancing, improved link reliability, frictionless movement, increased energy efficiency, availability of wireless connectivity in remote locations (such as deep space, deep ocean, and deep ground situations), improved security, and interference reduction are all important functions that hybrid networks can perform. As a result, these networks have received a lot of research attention. Both RF/optical and optical/optical wireless hybrid systems are possible in the terrestrial environment. There are numerous hybrid system combinations for both systems [11]. Two or more different OWC technologies make up the optical/optical wireless system. For an acoustic/optical wireless hybrid system in underwater communication, acoustic communication can be considered (UWC). Depending on the requirements, several hybrid system types can be selected for various communication settings. One key advantage of hybrid networks is the ability to construct multi-tier networks.

II. BACKGROUND

In recent years, there has been significant growth in wireless communication technologies, including Wi-Fi, Bluetooth, and cellular networks. However, the increasing demand for high-speed data transmission and the limitations of these wireless technologies have led to the exploration of alternative solutions. Optical wireless hybrid networks combine the advantages of optical and wireless communication technologies to provide high-speed data transmission, improved reliability, and security. The advantages of optical fiber and wireless communication technologies are combined in OWHNs, a new class of communication networks. OWHNs are an excellent choice for many applications, including video streaming, cloud computing, Internet of Things (IoT) devices, and smart cities, since they can offer high-speed and dependable connectivity, low latency, and low power consumption [12]. The optical layer, wireless layer, and network layer make up the three layers of the OWHN architecture. Using optical wireless converters, which change wireless communications into optical signals and vice versa, it is possible to integrate these three layers. Numerous advantages of the OWHN architecture include increased coverage area, reduced power consumption, minimal latency, and high-speed connectivity.

Optical wireless hybrid networks use a combination of optical and wireless communication technologies to provide high-speed data transmission. While wireless communication technology uses radio waves to convey data, optical communication technology does it using light waves. The use of optical technology in wireless communication can offer several advantages, such as higher data rates, reduced interference, and improved security [13]. The necessity for a communication infrastructure that can deliver dependable and high-speed connectivity in locations with little to no access to fiber optic cables gave rise to the idea for the OWHN. To create a scalable and effective communication infrastructure, the OWHN idea relies on the combination of optical and wireless communication technologies. While wireless communication technology offers the adaptability and mobility necessary for last-mile connectivity, optical communication technology offers high-speed and reliable data transmission over vast distances. Utilizing optical wireless converters, which change optical signals into wireless signals and vice versa, these two technologies are combined in OWHNs.

End users can take advantage of the vast coverage area that RF systems assure and the consistent rates that optical wireless systems provide with the RF/optical wireless hybrid system, which combines both RF and optical-based wireless technologies. Such networks are realistically possible since RF and OWC systems can coexist in the same space, like offices and rooms, without interfering with one another. The hybrid technique combines two or more technologies, for example, RF/optical, RF/FSO, wireless fidelity (WiFi)/LiFi, femtocell/VLC [14], power-line communication (PLC)/VLC, Bluetooth low energy (BLE)/OCC, VLC/FSO, LiFi/OCC, and acoustic/optical, and may offer some merits of both.

The limitations of traditional wireless communication technologies, such as Wi-Fi and cellular networks, have led to the exploration of alternative solutions. Optical wireless hybrid networks have emerged as a potential solution to provide high-speed data transmission, improved reliability, and security. However, the technology is still in its early stages, and there are several challenges and limitations associated with its implementation. The constraints of conventional wireless networks, such as their low data rates, high latency, and constrained service areas, are their main area of concern. Traditional wireless networks are also vulnerable to interference and security problems [15], which can impair network functionality and data security. Although optical communication technology may deliver high-speed and dependable data transfer over great distances because, of its high installation and maintenance costs, it is not appropriate for last-mile connectivity. Integrating these two technologies to create a seamless communication infrastructure that can get over the constraints of conventional wireless networks is the fundamental problem facing OWHNs.

Despite the benefits of OWC systems, there are some drawbacks, including a strong reliance on line-of-sight (LOS), a small coverage area, sensitivity to sudden connection loss, interference from various light sources, performance degradation from the outside environment, and limited amount of transmitted power. Therefore, getting around these restrictions is a difficult problem for a successful OWC deployment. Different local and international authorities strictly control the usage of an RF band (3 kHz-300 GHz). Interference is also a significant problem in RF-based communications [16]. Though improved mobility and better performance in non-line-of-sight (NLOS) situations are supported by wireless technologies based on RF. Some of the shortcomings of OWC systems can be solved by these unique RF system capabilities.

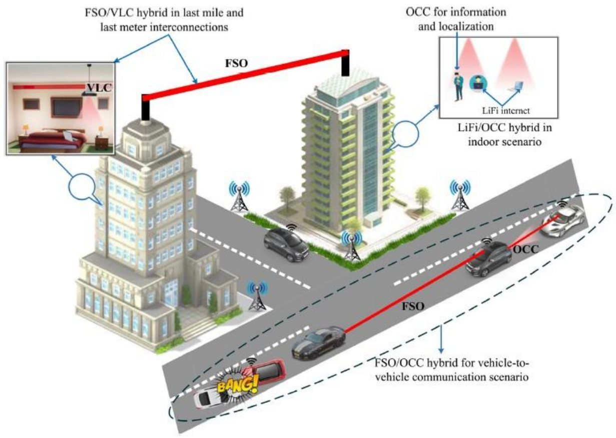

Fig. 3. Generic VLC RF/Optical System

A brief overview of the networks that are being considered for optical wireless hybrid systems [17]. Diverse RF and OWC technologies, underwater acoustic communication, and hybrid systems are all taken into consideration in this study. Based on how the associated waves behave in terms of transmission, emission, and absorption as well as their potential uses, the various categories of the electromagnetic spectrum have different names. For supporting OWC systems, a significant amount of the electromagnetic spectrum is available. VLC employs photodetectors (PDs) as receivers and LED luminaires or laser diodes (LDs) as transmitters. Using just VL as the communication medium, it may provide communication, lighting, and localization. With VLC, a 100 Gbps data rate has been accomplished [18].

It can be either point-to-point or point-to-multipoint and can be either unidirectional or bidirectional. VLC does not require the support of mobility or illumination. Sunlight and other light sources have a significant negative impact on VLC's performance, making it unsuitable for outdoor applications. Additionally, indoor VLC systems cause coverage gaps, and the communication range is short. A location where the received signal strength is so weak that communication between the transmitter and receiver is unfeasible is referred to as a coverage hole.

Like WiFi, LiFi is technology. Along with lights, it offers high-speed wireless connectivity. Like VLC, it offers communication, lighting, and localization and uses LEDs or LDs as transmitters and PDs as receivers [19]. A LiFi system provides bidirectional communication because the transmitter and receiver are present at both ends of the transmission. Additionally, point-to-multipoint connections are supported. LiFi requires the support of illumination and mobility. Communication is equally as seamless as other RF systems because the intensity modulation employed in LiFi cannot be perceived by the human eye. The impact of ambient light sources and sunlight on LiFi performance is very significant. In addition, indoor LiFi systems have coverage gaps. Typically, the same hybrid architecture can be implemented using the LiFi or VLC system [20]. The two most significant distinctions between the LiFi and VLC systems are that LiFi supports point-to-multipoint communication, whereas VLC is not required to support this feature, and that VLC uses VL as the communication medium, as opposed to LiFi, which uses VL for the forward link and VL or IR for the reverse link.

RF technologies may also be present in hybrid systems in addition to OWC technology. Below is a summary of a few well-known RF wireless technologies: RF small cell network: To provide high QoS, RF small cells, such as the femtocell network technology, are frequently implemented in subscribers' homes. A small-size cellular base station, such as the FAP, known as a small cell base station (sBS), is used to serve 6–8 users. The spectrum that has been licensed for cellular service providers is where the sBSs operate. Service providers can extend cellular connectivity to the cell edge with the use of small cell networks, especially in areas with constrained or non-existent access [21]. Small cell network traffic is backhauled using existing broadband networks, such as Ethernet, cable TV (CATV), and PLC networks. Small cell RF frequency spectrum is extremely important and requires effective management. Technologies for small cells are great ways to deliver the advantages of FMC.

Macrocellular network: This technology is primarily used outdoors where it may offer greater coverage and user mobility. Due to the MBS's limited capability to serve many customers and its inability to provide higher data rates, its priceless spectrum needs to be handled with extreme caution. Microwave-link network: Microwave-link communication systems transmit data quickly and over great distances between two places using a beam of radio waves in the microwave frequency range. demonstrates a 12.6 Gbps communication link. For remote places, a microwave-link communication system offers point-to-point communication and is a useful alternative to optical fiber access. It can establish a communication link at more than 100 kilometres. Weather factors like rain and solar storm can affect how well this connection performs.

Bluetooth is a wireless technology standard that uses short-wavelength radio waves in the 2.400-2.485 GHz range to exchange data at a rate of up to 2 Mbps across short distances. Both it's power usage and security level are quite low. RF-based wireless local area networking of devices using the IEEE 802.11 standard is made possible by WiFi technology. IEEE 802.11ad can handle data rates of up to 8 Gbps [22]. Even if numerous encryption systems are employed in this technology, there are security issues. The longest link range of any UWC technology is provided by underwater acoustic communication, which can transmit data underwater up to 20 km. However, this technology only supports data rates in the kbps range.

III. RF/OPTICAL WIRELESS HYBRID NETWORKS

A. Overview of Hybrid Systems

For the majority of indoor wireless applications, RF-based technologies like WiFi, femtocells, and Bluetooth as well as optical wireless technologies like VLC, LiFi, and OCC systems are now in general usage. Multi-tier HetNets use a combination of macrocells [23], which offer broader coverage and lower-data-rate services, RF femtocells, WiFi, and optical attocells, which offer increased capacity by utilizing the optical spectrum, for the majority of indoor cases. LiFi and VLC enable traffic offloading from licensed macrocells and/or RF small cells/femtocells that are under capacity stress. Thus, RF/optical wireless hybrid systems enable the benefits of several networks while overcoming the shortcomings of each network. WiFi, femtocell, and macrocell networks are all often referred to as RF in indoor applications.

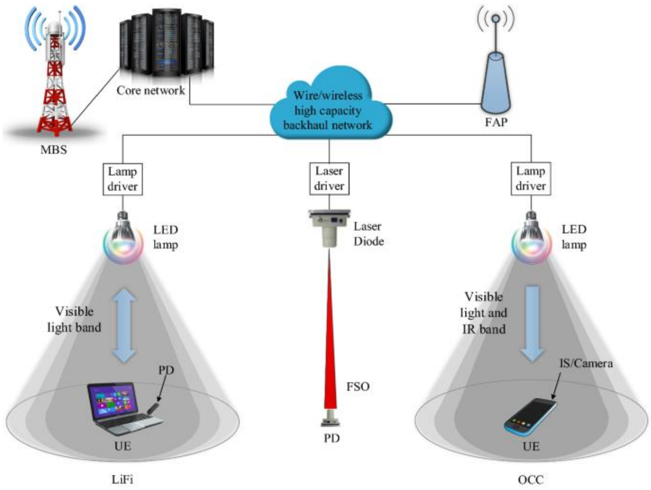

Fig. 4. Indoor RF/Optical Systems

Although both uplink and downlink communications are conceivable, VLC and LiFi cannot perform effectively for uplink communication because receiver devices like smartphones cannot be outfitted with high-power LEDs. The OCC only handles one way of communication; additional directions of communication are handled via LiFi, VLC, or RF networks. Through VLC and LiFi networks, all conceivable combinations of an uplink, downlink, and uplink/downlink are realized. The RF systems handle both uplink and downlink. Many important wireless communications goals are achieved by wireless hybrid systems, including increased throughput through load balancing, decreased interference through the co-deployment of opposing RF and OWC technologies [24], smooth handover between OWC systems through support for wider RF coverage, and increased linked reliability through the provision of both LOS and NLOS communication systems.

1. Small Cells and RF-Based WiFi Hybrid Systems

Hybrid systems allow for a variety of combinations when OWC technologies are combined with RF-based WiFi and small cells. Small cell/VLC, WiFi/LiFi, and hybrid WiFi/VLC, Systems for RF/OCC, small cells, and WiFi networks enhance the system efficiency. While WiFi and small cells offer comparably larger coverage for better mobile support, LiFi and VLC both allow high data rates. VLC and LiFi systems experience interference issues. LiFi and VLC networks leave coverage gaps that RF networks fill, making the changeover process more seamless. Through the same gateway, the RF and optical access points are linked [25].

2. Hybrid systems with Macrocells

WiFi or small cells are not always available in every indoor environment. The macrocell/VLC or macrocell/LiFi hybrid systems increase QoS [26] in these indoor environments. Background traffic with low mobility, high data rate, and relatively poor QoS is serviced by a LiFi or VLC network, whereas services with higher mobility and relatively better QoS are connected to a macrocell network in an interior setting. Furthermore, the macrocell network fills coverage gaps left by LiFi and VLC networks, smoothing the handover process. As a result, just like WiFi/VLC, small cell/VLC, WiFi/LiFi, and small cell/LiFi systems, macrocell/VLC and macrocell/LiFi hybrid systems support traffic offloading to high-data-rate and less expensive VLC and LiFi networks, networks, increasing spectrum utilization, connection dependability, optical wireless user mobility, and security.

B. RF/Optical Wireless Hybrid in Vehicular Systems

In V2X communications, connection stability is extremely important due to safety concerns. OWC provides a lot of benefits for V2X communications, however, its use is only in LOS. As a result, its integration with RF systems like 5.9 GHz dedicated short-range communications (DSRC) greatly enhances connection quality [27]. A developed technology, DSRC can offer significantly longer-distance communications. Other OWC technologies, except FSO, cannot offer comparable communication distances, but they are seen to have significant potential in areas with high traffic densities, and their wide geographic spread also indicates a major advantage. In contrast to OCC's support for a distance of 60 meters and FSO's support for even longer-distance point-to-point communication, VLC can handle extremely small distance inter-vehicle LOS communications. The messages are transferred in VLC using a multi-hop method for communications that take place over relatively longer distances. Multi-hop transmissions may result in an increased end-to-end (E2E) latency if we discuss high-priority communications [28].

For various V2X communications, RF/optical wireless hybrid systems can be used., which also illustrates certain application scenarios of RF/optical wireless hybrid systems in the car. With the assistance of the closest MBS, every moving vehicle transmits emergency information to a specific location (such as other moving cars or traffic infrastructures). The forwarding vehicle sends a signal to each camera installed on the vehicle using OCC, and the forwarding vehicle advances within the field of vision (FOV) of that camera. Additionally, this camera concurrently receives optical signals.

In such RF/optical wireless hybrid systems, the desired communication distance and environmental conditions may be considered while selecting a network. In RF/optical-based V2X communications, considering LOS/NLOS is a crucial factor in network selection. Long-distance communication with accurate pointing between the transmitter and receiver is supported by optical FSO [29]. OCC, in comparison, provides communications over medium distances, whereas VLC based on LED/PD only offers communications over short distances. A medium range of V2X communications is supported by the current RF infrastructure. Therefore, in an RF/optical wireless hybrid system, a network may be chosen based on the communication distance [30]. Fog, dust, and ambient lighting are just a few of the environmental factors that have a significant impact on optical systems. Therefore, choosing the right network also requires consideration of the environment's conditions.

Fig. 5. RF/Optical in Vehicular System

C. RF/Optical Wireless Hybrid in Free space

FSO gains popularity as a wireless communication system, particularly for the last-mile connection issue, due to its clear benefits, including exceptionally high accessible bandwidth, affordable deployment, and license-free spectrum. An extremely high data rate outdoor point-to-point communication link is offered by the FSO technology. However, this mechanism is severely hampered by atmospheric effects, particularly during times of air turbulence and visibility-reducing conditions like fog, snow, and dust. The FSO system, in particular, depends on the presence of a LOS, which places serious restrictions on mobile nodes. Another drawback of the FSO method is the tight aiming of the transmitter towards the PD [31]. The transmitter beam vibrates as a result of thermal expansion, dynamic wind loads, and minor earthquakes, which causes the FSO transmitter and receiver to be out of alignment. These restrictions can be avoided by combining RF technologies like microwave and mmWave connections. Rain harms mmWave and microwave RF communications. Additionally, very long-range, and high-speed communication cannot be accomplished with RF technology.

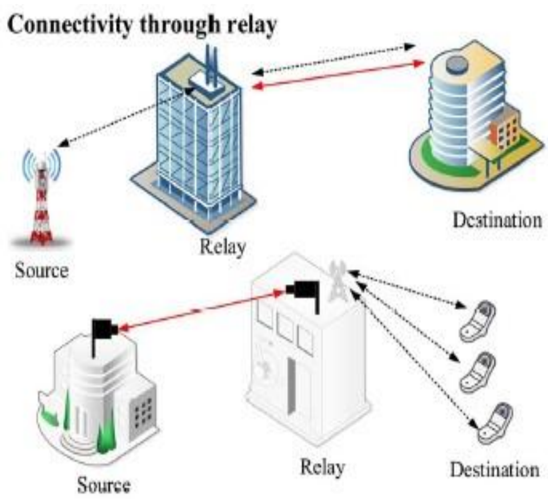

Fig. 6. RF/Optical in Free Space

Therefore, for the FSO/RF hybrid system, here is a possible solution to ensure connection reliability in different weather conditions. The FSO system is used as the primary network and the RF System acts as a secondary backup network for FSO/RF hybrid system. This hybrid system can be used for even very long-distance free-space communication systems such as airplane-to-airplane, inter-satellite, satellite-to-earth, earth-to-satellite, satellite-to-airplane, airplane-to-satellite, airplane-to-ground, ship-to-ship, and ship-to-infrastructure links with very high reliability [32]. To provide inter-networking with improved connection dependability, hybrid systems made up of two networks of RF and FSO links are employed. A key component of this hybrid system is the connection via the relay. The phrase "mixed RF/FSO network" also applies to this relay-based hybrid system.

This hybrid design guarantees improved connection dependability for various environmental situations for free-space communications. The capacity of this hybrid technology to maintain a link under even the most adverse environmental circumstances is its most significant advantage. It can function effectively regardless of the weather. The right network selection is crucial for hybrid RF/FSO connection since weather conditions vary dynamically. The environment's state and the desired communication distance are the two most crucial factors to consider when choosing a network in hybrid RF/FSO systems [33]. While rain has a significant impact on microwave and mmWave, fog, dust, and snow have a significant impact on the FSO connection. The FSO system may be used in regular weather, and a link can be chosen based on the weather's characteristics. In contrast to RF links, FSO can offer an even greater communication range. As a result, a network may be chosen based on the necessary communication distance.

D. RF/Optical and Acoustic/Optical Hybrid Networks in Underwater

Underwater wireless optical communication has advanced recently. Since (UWOC) is being considered for many possible uses, including environmental investigation of oil pipes, monitoring, and offshore investigation. Many UWC applications require long-distance, fast connectivity. Acoustics, RF, and optical are potential communication techniques for the ocean floor. Underwater communications based on RF and acoustic waves cannot enable high-data-rate communication links, in contrast to RF-based terrestrial communications. Since acoustic communication has the longest underwater communication connection range among all UWC technology up to 20 km it is a common technique for underwater wireless communication [34].

The data rate in this system is however limited since its frequency of operation range is between tens of hertz and hundreds of kilohertz. But the data rate in this system is in the kbps range only. The slow propagation rates of acoustic networks also make them sensitive to significant communication delays. Due to the severe consequences on components such as multi-path propagation, fluctuations in the time of the channel, and significant signal attenuation, particularly over long distances, RF has a very poor performance for underwater communications over long distances. As a result, the accompanying short link range places restrictions on RF systems. For a long-range UWC, the use of a 405-nm blue light laser diode is anticipated to be an important area. Within a 10-100 m range, optical communication devices can deliver a Gbps level LOS data-rate link. In comparison to other systems, UWOC has the lowest link delay, maximum communication security, highest transmission rate, and lowest implementation costs. These are all good technological benefits [35].

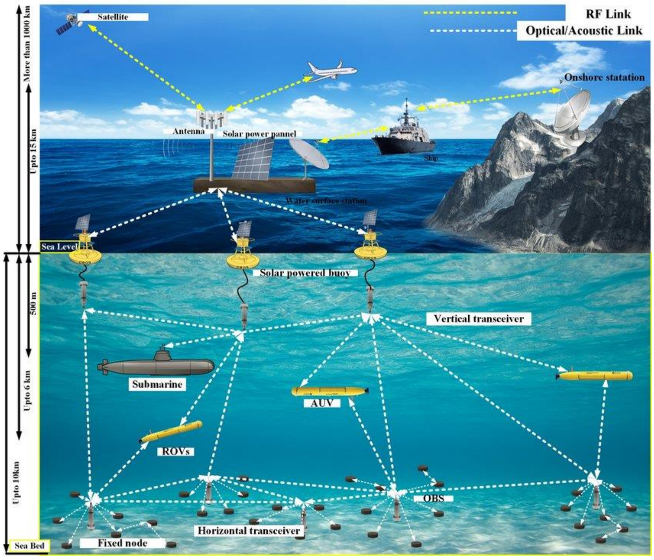

Fig. 7. Optical/RF in Underwater

Traffic offloading occurs in a hybrid system. While RF and acoustic networks are unable to provide a very high-capacity link as optical wireless networks, adding an optical network boosts the system's capacity. In an RF/optical hybrid system, the optical wireless system is capable of high-data-rate services for both long and short-distance communications, while the RF system can provide short-distance communication. Similar to this, in an acoustic/optical hybrid system, the optical wireless system supports high-data-rate LOS services while the acoustic system can be used for NLOS communications. In comparison with terrestrial communications, UWC has poorer link reliability [36]. Therefore, having two or more communication systems assures greater link reliability. The RF or acoustic system can function while the transmitter and receiver are lost in pointing, increasing the link reliability. The needed communication distance, traffic type, and accurate aiming of the optical connection are the three most crucial factors in choosing a viable network for underwater communications. While the RF system can only be utilized for very close proximity communication, the acoustic system may be used for extremely long-distance communication. With its ability to enable high-data-rate communications across long distances, UWOC calls for extremely accurate pointing between the transmitter and receiver. Therefore, connections can be supported under conditions requiring accurate pointing. UWOC, and by RF or acoustic systems in other situations.

E. RF/Optical Wireless Hybrid in eHealth

In healthcare systems, having an effective monitoring system in place is crucial. The majority of countries are currently emphasizing improving their healthcare systems. Wearable sensors or patches with network connectivity are required for any potential eHealth solution to be successful. RF-based BLE technology [37] is now being used for this communication. The use of current RF technology for eHealth solutions has several drawbacks. Much medical equipment is particularly susceptible to electromagnetic interference, which can cause device failure. RF for healthcare solutions creates substantial electromagnetic interference outcomes. In NLOS circumstances, BLE offers a communication link, however. A possible additional option for wearable sensors and patches to obtain network connectivity is an OCC system. The biggest drawback of this is that the link is unavailable when there are NLOS circumstances..

Therefore, in future eHealth systems, a hybrid system with OCC and BLE might be a desirable option for patch connectivity-based real-time health monitoring. The sensors are coupled to a skin patch that includes an OCC and Bluetooth Low Energy module [38]. The skin patch that houses the sensors has an integrated OCC and BLE module. For RF and OCC communication, this patch may be linked to a camera and the BLE module, respectively. In NLOS circumstances, the OCC cannot function. The patient is connected to the OCC system during the LOS condition, and to BLE during the camera NLOS state.

F. RF/Optical Wireless Hybrid in Positioning/ Navigation

For localization, positioning, and navigational reasons, optical and RF technologies are both used. In the LOS condition, the localization accuracy in VLC, LiFi, and OCC is higher than in the WiFi system. In NLOS circumstances, the WiFi technology offers improved accuracy. Directional optical networks enhance interior positioning in a centimetre range as compared to RF-based systems [39]. The performance of an optical-based device, however, suffers greatly in NLOS conditions. Additionally, optical devices function poorly in outdoor settings under a variety of weather conditions. The total performance of indoor and outdoor localization, positioning, and navigation is therefore improved by the cohabitation of omnidirectional RF technologies with directional optical wireless technologies. LEDs may be used to locate a smartphone in an indoor setting. A combined RF/optical wireless system increases localization performance.

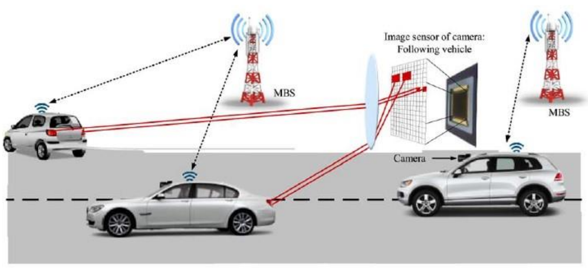

Fig 8. RF/Optical in Navigation

When employing OCC, the smartphone camera gets signals from more than two LEDs that are inside the camera's field of view. Received signals contain much information such as the physical size of LEDs and their coordinate data (i.e., x-, y-, and z-coordinates), which help to determine the distance between the camera and the LEDs using photogrammetry [40]. The position of the smartphone is always changing; therefore, every estimated position information is sent to the lighting server using the WiFi access point. The lighting server eliminates the localization estimation problem by calculating the smartphone's next likely position. A very high level of reliability is offered by the RF/optical wireless hybrid technology used for communication. The precision of localization is also improved by the presence of two systems. When choosing a network for a localization, positioning, or navigation application in an RF/optical wireless hybrid system, LOS/NLOS and environmental conditions are crucial considerations.

G. RF/Optical Wireless Hybrid Systems for Backhaul Network Connectivity

In 5G and beyond communication systems, it is difficult to provide a high capacity backhaul infrastructure that can handle a huge node density and deliver a lot of aggregated data. The essential issues of backhaul architecture efficiency are discussed concerning the expected huge data requirements of 5G and the vast connectivity of IoT [41]. The four main categories of backhaul lines now in use are copper wire, radio links (such as mmWave and microwaves), optical fiber, and FSO links. Despite the significance of wired backhaul options in 5G and future communication systems, such as fiber optics, they are not particularly important to this article.

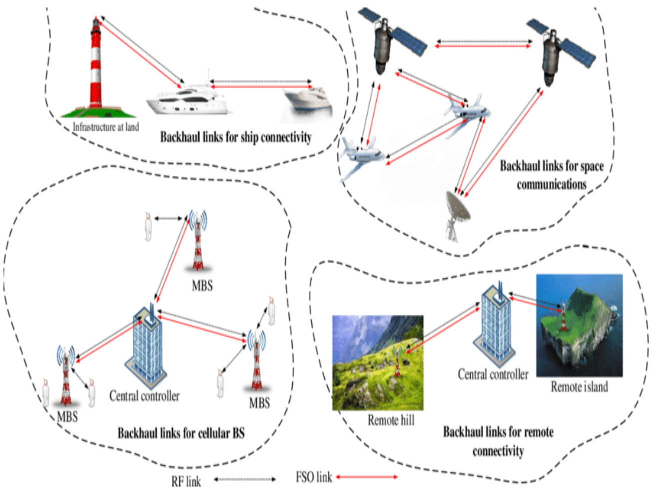

Fig 9. Backhaul RF/Optical Network

For the backhaul network, copper lines have historically been the most used technology. T1 and E1 copper lines offer modest data speeds, but (1.544 Mb/s for T1 and 2.048 Mb/s for E1). Due to the requirement for several parallel connections, costs increase linearly with available capacity. Therefore, copper technology becomes highly costly and is no longer a viable alternative for large data rates in 5G and beyond communication networks. Over long distances, optical fiber is a high-data-rate option that can enable communication lines that are more than 10 Gbps. Due to the high deployment costs, particularly in extremely dense environments, the installation of optical fiber-based backhaul connectivity is at times limited [42]. In some restricted areas and applications, it may even be impossible due to remote connectivity and cable installation restrictions. In regions where installing wired connections is not practical, optical fiber or other wired backhaul connectivity is not an option. For backhaul connectivity, wireless technologies offer a practical substitute for copper and optical fiber networks, particularly in places where the installation of wired connections is difficult. Since an FSO system can provide high-data-rate backhaul connectivity, it is a good substitute for the optical fiber connectivity currently being used for backhauling lines [43]. Additionally, the use of comparable optical transmitters and detectors for FSO.

FSO backhaul has a capacity that is equivalent to optical fiber, however, it is substantially less expensive to deploy. The simplicity of deployment, interference-free nature, speedy setup, and cheap maintenance costs of FSO backhaul are other advantages [44]. However, air turbulence and atmospheric loss brought on by adverse weather, such as fog, snow, and dust, hurt the FSO system's performance. It requires a clear line of sight (LOS) path; hence it has a transmitter-receiver misalignment issue. On the other hand, whereas RF-based mmWave and microwave communications are significantly harmed by wet weather, they are not much harmed by fog, snow, or dust. Therefore, combining an RF system with an FSO backhaul system to create an FSO/RF hybrid backhaul system is the ideal way to increase connection reliability. For high-data-rate backhaul communication with better link stability, the RF/FSO hybrid system can be employed. The RF system can serve as a secondary backup and the FSO system as the main backhaul network.

IV. ADVANTAGES OF OWHNs

Over conventional communication systems that just use optical or wireless technologies, optical wireless hybrid networks (OWHNs) have a number of benefits. OWHNs' capacity to offer high-speed connectivity, low latency, and scalability is one of their key advantages [45]. OWHNs are substantially quicker than standard wireless networks at providing data transmission rates of many Gbps. OWHNs are the best choice for real-time communication-requiring applications including video streaming, online gaming, and teleconferencing due to their low latency. OWHNs are also suited for applications in smart cities and IoT devices due to their scalability, which enables them to accommodate numerous users and devices at once.

OWHNs' adaptability and deployment simplicity are further benefits. OWHNs are different from conventional optical networks in that they don't need pricey fiber-optic infrastructure, which may be time-consuming and expensive to establish. Instead, OWHNs can be installed utilising inexpensive optical wireless transceivers that are simple to attach on structures like buildings. OWHNs can also be swiftly set up in emergency scenarios like natural disasters where damaged or unavailable traditional communication networks may occur [46]. In addition, OWHNs are less prone to interference than conventional wireless networks. This is so because unlike conventional radio frequency transmissions, optical wireless signals are less impacted by weather elements including rain, fog, and snow. OWHNs can therefore offer a more dependable communication infrastructure in regions with unpredictable weather. OWHNs are additionally energy- and environmentally friendly. OWHNs don't use a lot of energy to transport data across vast distances, in contrast to standard wireless networks. OWHNs also do not produce hazardous electromagnetic radiation, which may worry some people.

In conclusion, high-speed connectivity, low latency, scalability, flexibility, ease of deployment, immunity to interference, and energy efficiency are only a few benefits that OWHNs have over conventional communication systems. OWHNs are a desirable alternative for a variety of applications, including video streaming and teleconferencing as well as smart cities and Internet of Things (IoT) devices. OWHNs [47] have the ability to completely change how we communicate and access information with more research and development.

V. CHALLENGES

Several issues must be solved efficiently for the successful deployment of different hybrid systems. Some important challenging issues and future directions for optical wireless hybrid systems are briefly discussed below

A. Network selection

An effective network selection technique is essential for the hybrid system. While a hybrid wireless network increases system performance, the combination of multiple wireless technologies complicates access network selection. This issue in a heterogeneous network is always more complicated than in a homogeneous network [48]. In homogeneous networks, a straightforward network selection method is selecting the network providing the strongest signal to the user. However optical wireless hybrid systems comprise two or more heterogeneous technologies, and these technologies may differ in terms of RF and optical wireless technologies. Thus, the complexity of the involvement of many factors makes network selection challenging. The ideal network selection decision varies depending on the environment, and fine-grained intelligent network selection algorithms are necessary to assure good user QoE [49]. The network selection criteria differ for different optical wireless networks as well as differ considerably compared to those of existing RF-based networks. Different heterogeneous parameters should be considered for network selection in hybrid systems. This is a difficult job of network selection in a dynamic and uncertain environment for real-world hybrid system implementation. Careful selection of such parameters as well as an efficient selection policy is vital to harness the benefits of hybrid networks. Moreover, computation time should be considered to minimize the delay. Although several researchers addressed this issue in their theoretical works, the successful deployment of hybrid RF/optical and optical/optical network systems is still a challenging issue.

B. Access Protocol

User mobility is critical for future wireless networks. The user travels both indoors and outdoors, making focusing the mobile receiver and the integration mechanism between the LED transmitter and the RF-BS critical issues in the access protocol. Rather than RF/optical wireless hybrid networks, the CSMA/CA protocol has been introduced separately in various current publications for single-network applications. As a result, more study is needed to create the CSMA/CA protocol [50] of various wireless hybrid systems. The design of medium access control algorithms for uplinks in RF/optical and optical/optical wireless hybrid networks also has a wide range of potential contributions

C. Handover

It is a crucial aspect of a hybrid system. Despite extensive research into effective virtual hands-on systems for RF communications, the nature of an optical channel due to users' unpredictable mobility makes the virtual hand between RF and optical wireless networks more challenging than in an all-radio setting. The physical and data-link layer features and methods differ across such heterogeneous optical and RF-based wireless networks [51], posing a significant challenge to hybrid system mobility management. Appropriate handover decision criteria and algorithms continue to be important research problems in optical wireless hybrid networks. User mobility and its impact on channel estimates and handover are among the concerns. Obstacles can cause channel blockage in optical wireless systems, making targeting the network during the changeover a crucial aspect. To meet the specifications of the 5G need, the handover should be brief.

D. Load balancing

A technological problem for hybrid networks is effective to load balancing. The first significant difficulty in optical hybrid networks is assigning users among the many access networks available [52]. Finding the best user association solves a combined association and resource allocation problem [53]. During a call session, the load-balancing process must be conducted regularly. Users may need to be shifted to various better-serving access points during user migration, and a handover may be required. Considering all of this, optimal load balancing in a hybrid network is a difficult problem to solve.

E. High-capacity backhaul network

The provision of high-data-rate applications and extensive connection by hybrid networks results in a tremendous quantity of total data throughput in the access network. An extremely high capacity backhaul is still an active and demanding research subject for facilitating this data flow [54]. A hybrid system has numerous transmitters, allowing for seamless steering of sent data. The data transfer to the target recipient changes due to a variety of factors such as a change in the communication environment, data type, and user mobility [55]. Furthermore, access point assignment and flawless data steering have emerged as major challenges in hybrid networks. This issue's main issues are data loss minimization, optimum transmitter selection, and latency minimization.

VI. FUTURE SCOPE

The field of optical wireless hybrid networks is still evolving, and there is a need for further research in this area. Future research can explore the implementation of the technology in different applications and investigate potential limitations and challenges. OWHNs have a bright future since they can offer a flexible and effective communication infrastructure that can satisfy the needs of contemporary communication systems [56]. Future research in OWHNs will focus on a variety of topics, such as the creation of new, more efficient optical wireless converters, the integration of OWHNs with cutting-edge technologies like 5G and Li-Fi, and the creation of brand-new routing and switching algorithms for the network layer [57]. Furthermore, the installation of OWHNs in isolated and rural locations can grant access to high-speed internet, which can foster social and economic development in these regions. OWHNs could fundamentally alter how we communicate and receive information.

As a result, OWHNs may be able to offer a flexible and effective communication infrastructure that may satisfy the needs of contemporary communication systems. However, several of the issues with OWHNs, like their sensitivity to atmospheric conditions and interference, need to be resolved before their wide-scale deployment [58]. To create new technologies and algorithms that can boost OWHNs' functionality and dependability, more study is required. OWHNs can completely change how we communicate and access information with more research and development. In summary, OWHNs have the power to completely change the way we interact with one another and obtain information. Some of the OWHN-related issues must be resolved before their wide-scale adoption, though [59]. To create new technologies and algorithms that can boost OWHNs' functionality and dependability, more study is required [60]. OWHN deployment can offer scalability, low latency, and high-speed connectivity, which helps improve the performance of these applications. OWHNs can offer a scalable and effective communication infrastructure that can satisfy the needs of contemporary communication systems with further study and development.

VII. CONCLUSION

This paper provides insight into the trends, opportunities, challenges, and research directions of optical wireless hybrid networks. It presents an overview of the background of the technology, the problem statement, and the proposed approach. Additionally, it discusses the potential applications of optical wireless hybrid networks and concludes with future scope in the field. By combining the benefits of optical and wireless communication technologies, OWHNs can offer a solution to the problems that traditional communication systems encounter. OWHNs can offer scalability, low latency, and high-speed connectivity, all of which are critical for contemporary communication systems. We gave a general review of OWHNs in this article, along with some of their benefits and drawbacks. We also talked about some of the current directions for OWHN research, including the creation of novel optical wireless converters, their integration with 5G and Li-Fi technologies, and the creation of fresh routing and switching algorithms. Different OWC technologies have recently emerged as a key component of the wireless communication system since RF systems are unable to meet the diverse expanding needs of 5G and beyond communication systems. OWC is a prospective alternative to RF-based wireless communication systems because of its exceptional qualities. The limits of a single network can be solved by co-deploying two or more networks with distinct features. Therefore, many limitations of either RF or optical wireless-based single networks can be solved by hybrid systems that combine an optical wireless system with RF or another optical technology. Research is being done on the remaining difficulties associated with using various hybrid wireless networks.

The main research questions for optical wireless hybrid networks are covered in this review study. The opportunities presented by hybrid architecture scenarios are also covered. Research on RF/optical, optical/optical, and acoustic/optical wireless hybrid network systems is summarized in this term paper. RF-based macrocells, small cells, WiFi, BLE, and optical-based VLC, LiFi, OCC, and FSO communication technologies are taken into consideration for various combinations of hybrid systems. Discussions are had regarding network design, network choice, and application scenario potential brought about by these hybrid systems. This article considers several application scenarios including indoor, automobile, space, eHealth, and underwater. Additionally, the main areas of study for various hybrid network systems are mentioned. Also briefly mentioned are the significant obstacles that must be overcome for the effective implementation of hybrid network systems for 5G and beyond as well as IoT paradigms. This term paper is completed by highlighting how tight integration across counterpart networks and an examination of cutting-edge research trends that are not yet fully resolved could further enhance the performance of optical wireless hybrid systems. To successfully deploy OWC systems as a promising complement to RF-based technologies in future 5GB communication systems, further efforts are expected to be stimulated by this review paper, which will aid in understanding the research contributions in various optical wireless hybrid systems.

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