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Emerging 5G/6G based Optical Wireless communication for IoT Applications

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ABSTRACT
The next generation 5G/6G communications will surely bring about huge advancements as compared to the currently existing 4G communications. The 5G/6G communication systems will be able to deliver 1000 times higher system capacity, high connectivity, end-to-end network latency and quality of experience, reliability, security, lower energy consumption and so on. Internet of Things (IoT) connected devices will also play an integral part in the 5G/6G communication networks. The 5G requirements can be met by the use of optical wireless communications such as VLC, optical camera communication, Li-Fi technology as well as FSO communications. In this paper, the implementation of OWC systems for different IoT applications under 5G/6G is described.

KEYWORDS 5G/6G, Optical Wireless, IoT

I. INTRODUCTION

THERE has been a great increase in the number of networked devices worldwide surpassing the population numbers of people. In addition, the IoT connectivity is anticipated to go into about 50% of all networked devices via machine-to-machine technology, while internet usage will continue to grow. Subscribers' demands for bandwidth are rising steadily and are expected to attain 4.8 zettabyte each year in 2023. 5G speeds are anticipated to be much faster than the current average mobile connection speed; the mobile network speed is going to approach wireless fidelity and broadband wire connectivity speed to support many practices and applications. There will be approximately 34.2 billion connected devices in 2025 out of which, approximately 21.5 billion are expected to become Internet of Things (IoT). As shown in Fig. 1 below, in 2018, it was forecasted that by 2023, there would be four times public Wi-Fi hotspots in addition to residential hotspots; altogether 628 million hotspots. Furthermore, from 2017 to 2022, global mobile data traffic will grow by about seven times to 77.5 exabytes [1].

Non-IoT comprises different mobile phones, PCs, tablets, laptops, as well as fixed line phones. IoT comprises all consumers and B2B devices that are connected. In case of the tremendous connectivity of devices in the case of IoT, the OWC technologies can become critical for sensing and resource sharing. There are numerous interesting features of OWC technology that give rise to its tremendous potential,

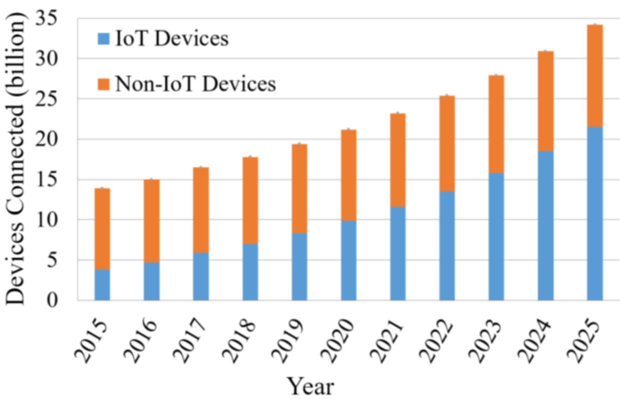

Figure 1. IoT and non-IoT devices [2]

which include low power consumption and high security; huge spectrum license-free and its spatial locality, thus giving rise to tremendous benefits with regard to data rates, spatial reuse etc. [2]–[7].

Efficient use of 5G technology requires reduction of the overhead associated with speculative parallelism [8], [9]. In this context, speculative parallelism is referred to as a technique where multiple tasks are executed in anticipation of the requirements of the future. This optimization is essential to enhance the overall efficiency of 5G networks and support the growing demands of high-speed data transmission and low-latency applications.

The integration of 5G and deep learning [10], [11] will pave the way for innovation in fields such as autonomy, healthcare, industry, transportations, and entertainment. With the integration of high speed connectivity and edge computing with intelligent networks and distributed learning, real-time decisions can be made through learning collaborations. CNN (Convolutional Neural Network) [12], [13], which is used for image recognition purposes, along with 5G technology, can be used for the transformational process of processing speed and connectivity. With the help of cloud computing [14]–[16] along with 5G, computation intensive tasks can be offloaded to cloud computing. It makes the data processing task easier and provides real-time data analytics and storage services.

The use of AutoML [17] in 5G technology integrates the two technologies to provide fast and low latency connections alongside automation of machine learning processes. With the integration of AutoML in 5G, applications that require machine learning benefit from real-time data transmission, increased speed in model training, and inference processes. Machine learning can also enhance the allocation of network resources in 5G networks leading to efficiency and improved user experience. There are many potentials that arise from the use of AutoML in 5G, particularly for autonomous vehicles, smart cities, and IoT.

Machine learning models, alongside unrolling factor prediction algorithms [18], can be used to improve 5G performance. The use of the machine learning process in predicting the optimum unrolling factor will help determine network parallelism. Based on this, network resource allocation will lead to increased throughput and decreased latency in 5G. The integration of the two technologies will provide effective utilization of 5G networks.

The complementary relationship between SDN [19], [20] and 5G network technologies makes it possible to make the best use of both technologies for improving network performance and realizing new capabilities. The ability of SDN technology to provide centralized management and programmability allows to improve the performance of 5G networks with respect to dynamic traffic engineering, efficient resource allocation, and network slicing. The integration of network services with SDN programmable interfaces makes it possible to design and implement new services using 5G capabilities.

This paper reviews the advances made in OWC technologies, including VLC, OCC, Li-Fi and FSO communication and LiDAR technologies, which are necessary to support the development of 5G and beyond. Quite a number of OWC methods are under consideration to meet the requirements for 5G and beyond networks. Although some of them have already been applied, the others remain to be at their early stage of development. This paper will start from an overview of the existing OWC methods in Section 2 and continue with the application areas of OWC technologies in Section 3, followed by conclusions in Section 4.

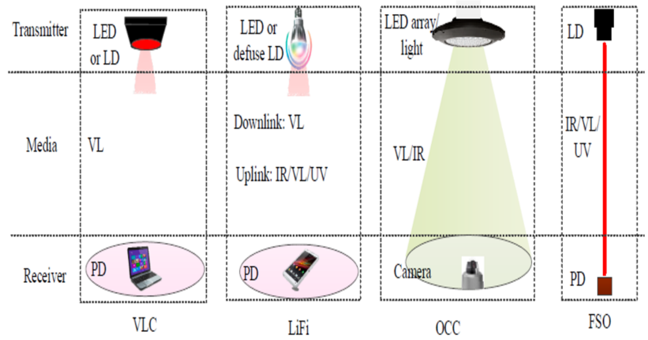

Figure 2. OWC technologies for IoT based 5G/6G systems

II. OWC TECHNOLOGIES

Optical Wireless Communication (OWC) is one of the future wireless technologies where the visible light (VL) or invisible infrared (IR), or ultraviolet (UV) is modulated as well as transmitted for carrying the data over the unguided medium. This wireless technology works in a broad range of the license-free spectrum of the Ultraviolet (UV), Visible Light (VL), as well as Infrared (IR). Therefore, it can be used in numerous indoor, space, terrestrial, and even underwater applications. This optical wireless communication is a practical solution for the development of the hybrid systems when the optical communication is performed underwater with acoustic communication or wireless sensor networks (WSNs) called underwater WSNs. In addition, OWC and Radio Frequency (RF) operate orthogonally thus reducing the interference since there are many interconnected devices, and they may interact with navigation or avionics systems [2]–[7].

OWC Technologies refer to Optical Wireless Communications where optical waves are employed for wireless data transfer. WiMAX [21] refers to Worldwide Interoperability for Microwave Access (WiMAX), a long-range broadband access wireless technology using radio frequency.

OWC technologies such as VLC, Li-Fi, OCC, and FSO can be considered most appropriate for meeting the demands of +5G and IoT communications. In addition, the technological differences in transmitters, receivers, and communication media are illustrated in Fig. 2. In VLC, the use of photodiodes (PD) is made as receivers, whereas LEDs or LDs serve as transmitters (Tx). The unique feature of VLC technology lies in the fact that the only communication medium employed there is VL. Li-Fi technology has much to do with WiFi; it offers a wireless connection that is lit with high speed, using LDs or PDs for Tx and Rx. Both VL and infrared radiation (IR) are used as the communication channel in the forwarding and returning links, respectively. As a rule, due to the absence of high-power LEDs, the uplink in VLC or Li-Fi technology does not show good results; in smartphones, for example. LED arrays serve as the transmitter for OCC, while cameras or image sensors are used as receivers. Photo- and video data are captured by complementary metal-oxide semiconductor cameras. It can either have a rolling shutter or a global shutter. The medium of communication for OCC would be either VL or IR, while the UV range can be used for the communication process. LD and PD are usually employed as the transmitter and receiver in FSO technology, respectively. Nevertheless, heterodyne optical detection Rx [22]–[25] is also employed for FSO communication. This system is usually operated using the transmitter and the receiver, respectively. Nevertheless, FSO communication also makes use of heterodyne optical detection receiver. This system can be operated with VL and UV, but IR is mainly used for FSO communications [26]–[34].

The performance measure comparison of the several OWC technologies is shown in Table 1. These technologies' distinctions from one another are fairly clear. The utilisation of visible light as a communication medium is what makes VLC special. Bidirectional communication, seamless mobility, point-to-multipoint and vice-cersa communications are all requirements for a LiFi system. Only the OCC system out of all the OWC technologies uses image sensor working as a receiver. Because LD transmitters emit focused, narrow beams of light, an FSO system may be able to establish both a long-distance and a high-transmission-rate communication channel [35], [36].

III. APPLICATIONS OF OWC TECHNOLOGIES FOR 5GB INTERNET OF THINGS SYSTEMS

The electromagnetic spectrum's RF band spans the range of frequencies from 3 kHz to 300 GHz. Somehow, because of the beneficial communication qualities in RF range, the GHz spectrum is frequently utilized by recent wireless schemes. These are insufficient to fullfil the enormous needs of the 5G based IoT networks, this band is practically depleted. The municipal, national, and international authorities all impose tight regulations on it [2]–[7].

Numerous OWC technologies can be utilized to establish a wide variety of communications applications, consisting machine-to-machine, chip-to-chip and point-to-multipoint. In addition to ultra-short-range interconnects using FSO systems as well as in-body networks utilizing LiFi, VLC, OCC, medium-range, short-range, indoor positioning, inter-building networks, backhaul connectivity with long-range connectivity are all made possible by light. The shortcoming of OWC system is the obstruction of communication because of line-of-sight (LOS) communication. The majority of drawbacks of particular RF-based as well as wireless communication can be effectively addressed by the cohabitation of the two networks [22]–[25].

A few notable 5G/6G as well as IoT systems utilising OWC technology are shown in Fig. 3. The OWC networks can support all of our life's platforms, including cellular connectivity, satellites conectivity, space communication, underwater communication, electronic health, and smart homes.

According to transmission distance, OWC services are categorised in Fig. 4. Wide area networks (WAN), wireless

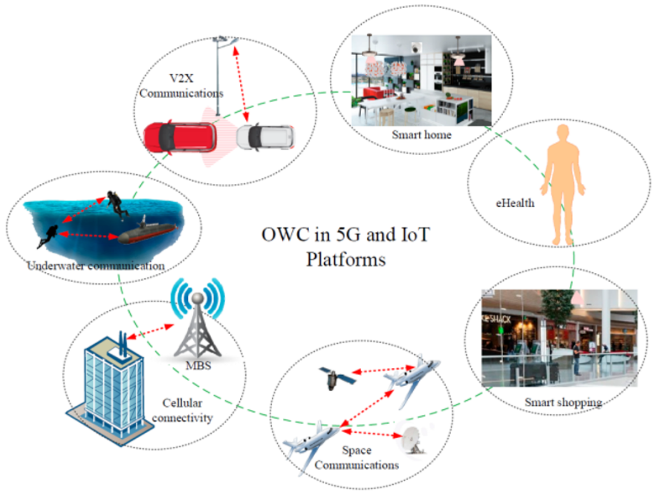

Figure 3. OWC technology for IoT systems and 5G/6G networks

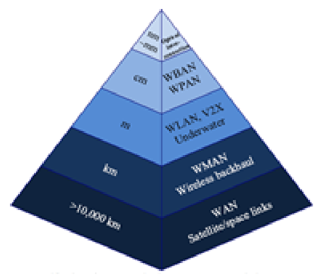

Figure 4. Application classification for OWC depending on transmission distance

metropolitan area networks (WMAN), wireless personal area networks (WPAN), and other wireless networks can all employ OWC (Chowdhury et al., 2018, Uysa, 2014)

Various possible applications of OWC systems for various communication ranges have been illustrated in Fig. 5. The illustration proves that numerous types of communications, ranging from ultra-short distance inter-chip and ultra-long distance inter-satellite communications, can be established using OWC.

Fig 6. illustrates some cases of application scenarios involving indoor and outdoor VLC and Li-Fi technology deployments. The application scenarios for Li-Fi and VLC technology are similar. Here, both communication and illumination activities occur simultaneously indoors. In some cases, both activities occur simultaneously outdoors (for instance, in the case of outdoor lighting and headlights of vehicles), while in some cases, only communication occurs. Depending on supported communication media for upstream and provided functionalities, as shown in Fig. 6(a) for Li-Fi and VLC communication. One possible scenario of Li-Fi/VLC communication is streetlight-to-mobile phone communication, as shown in Fig. 6(b). However, examples of VLC technology include communication between infras-

Table 1. Comparative performance metrics of several OWC technologies

Issue	VLC	LiFi	OCC	FSO
Topology	Unidirectional or bidirectional	Mustbe bidirectional	Unidirectional	Unidirectional or bidirectional
distance	20m	10m	60m	Greaterthan10,000km
Mobilitysupport	Optional	Must	Optional	No
Effect	Indoors:NoOutdoors:Yes	Outdoor	No	Yes
Interference	Minimum	Minimum	Zero	Minimum
Data rate	10GbpsusingLEDand100Gbpsusing LD	10Gbps using LED and 100Gbps using LD	55Mbps	40.665Gbps
Security	High	High	High	High

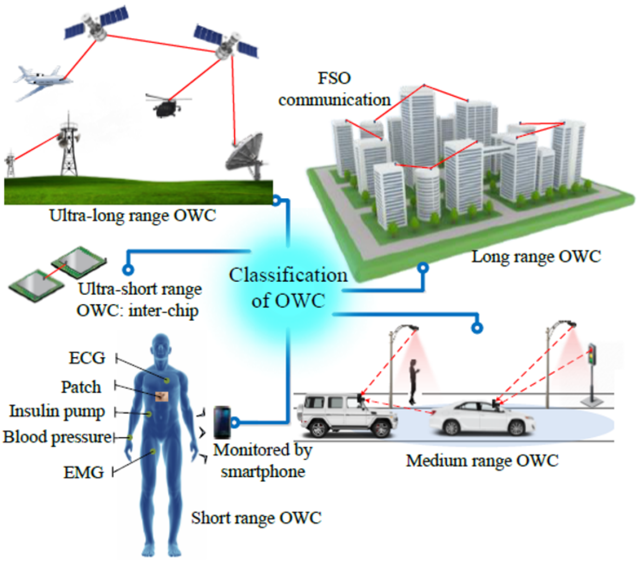

Figure 5. OWC for several transmission ranges

tructures and vehicles, communication between two vehicles, communication between vehicles and infrastructures etc [26]–[34]

When a VLC system uses LEDs and image sensor (IS) as its Tx and Rx, respectively, it can be regarded as an effective OCC system. When an OCC system uses VL as the communication medium, it can also be thought of as a VLC. The working principle of OCC system is depicted in Fig. 7. Here, the data is transmitted from two individual LED transmitters i.e. a traffic light as well as vehicle back LED array which can be readily or simultaneously stored by incorporating IS. By segregating the pixels connected to such noise sources, such as ambient light, digital signage, and sunshine, these background noise sources can be eliminated. By doing this, IS can offer dependable, uninterruptible, and secure communications even in outdoor settings. A few OCC system applications are shown in Fig. 8. There are numerous indoor and outdoor applications for the OCC system. Viewers can use the cameras on their smartphones to read information from digital signatures. A camera is employed to collect the wearable skin patches' tracked information. OCC technology allows for extremely accurate indoor and outdoor localization at the centimetre level. OCC offers excellent potential for V2V, V2I, and I2V communications. Data sharing for mobile users is possible with OCC technology. Motion detection and recognition can be done with OCC. Body motion can be used by the user to provide control signals, and OCC can be employed to detect the signals [26]–[34] .

Figure. 9 illustrates some application examples of FSO systems. As shown in Figure 9, there are nm optical connection, connectivity in buildings, cellular backhaul, underwater connectivity, communication with ships, satellite communication, and even airplane to Earth or vice versa communications using FSO techniques. One remote sensing method that appears attractive in terms of its use for measuring the distance to the target object and/or some additional information related to it is LiDAR [26]–[34]. Images provided by LiDAR include NIR as well as VL. Rain, dust, aerosols, non-metallic objects, clouds, chemicals, and even molecules are a couple of materials which could serve as LiDAR targets. Data acquisition for LiDAR is performed on the surface of the earth, aircraft, and satellites. The most widely used configuration for airborne LiDAR scanning is presented in Figure 10. Such areas of application as weather conditions, vehicles, transport monitoring, military operations, construction, robot vision, space research, navigation, anti-collision of vehicles could make use of LiDAR technology. According to recent studies, LiDAR systems are now providing up to 1.6 million 3D points per second for localization and obstacle detection applications [35], [36]

IV. CONCLUSION

The 5G communication was developed in 2021, while the 6G network is expected to come in the year between 2027 to 2030. Attaining the objectives of IoT-enabled 5G+ systems is a difficult task to achieve. Hence, the most important problems for the achievement of success are creating enough capacity, efficient communication, minimum delay, adequate security, reduced energy use, effective and reliable interconnection among other challenges in developing 5G communication network. The radio frequency network systems cannot meet the rising needs of 6G-enabled IoT networks. OWC solutions are thus more suitable than RF networks in the attainment of the future network objectives. Both optical and RF combined systems can achieve future network objectives for 5G and 6G. This paper evaluates different OWC solutions

(a) (b)

Figure 6. Major applications of LiFi/VLC systems for (a) indoor, (b) outdoor environments.

Figure 7. Working principle of OCC system.

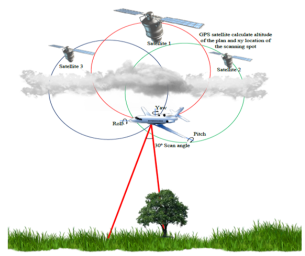

Figure 10. LiDAR application in airplane

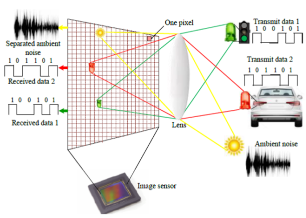

Figure 8. Applications of OCC system

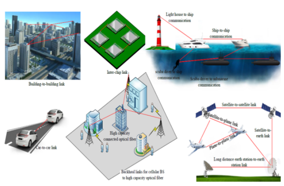

Figure 9. Application scenarios of FSO systems.

such as LIFI, VLC, OCC, FSO as well as Lidar in order to provide an alternative technology for 5G+ IoT network deployments. This system could be deployed in ultra-short to long distance communications. A comparative analysis of these technologies would be considered an adequate source of information in the understanding of different innovations in OWC systems. Therefore, optical wireless technologies are promising technologies that could improve future life.

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