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Emerging Technology for 6G Networks

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Abstract**—**Due to the rapid advancement of technology, there is an increasing demand for wireless connections that are both fast and reliable, with minimal latency. New wireless communication standards are developed every decade, and 2030 is expected to see the introduction of 6G. The primary objectives of 6G network and terminal designs are focused on sustainability and environmental friendliness. The International Telecommunication Union-Recommendation division (ITU-R) has established the minimum requirements for 6G, with peak and user data rates of 1 Tbps and 10-100 Gbps, respectively. In this context, Light Fidelity (Li-Fi) technology is the most promising candidate to meet these requirements. This article will explore the various advantages, features, and potential applications of Li-Fi technology, and compare it with 5G networking, to showcase its potential impact among other emerging technologies that aim to enable 6G networks.

Keywords**—**6G Networks, artificial intelligence, AI, Li-Fi technology, terahertz communication, visible light communication.

I. Introduction

SIX generation (6G) technology is the successor to 5G wireless networks and will operate at even higher frequencies. It promises to deliver significantly lower latency and increased capacity, with the goal of enabling one microsecond latency communication, which is 1000 times faster than other networks [1]. Additionally, 6G is expected to make better use of the available spectrum, resulting in a 5 to 10 times improvement in peak spectrum efficiency compared to 5G.

5G offers three main communication options, namely massive machine type communications (mMTC), enhanced mobile broadband (eMBB), and ultra-reliable and low latency communications (uRLLC). Key features of 5G include a user experienced data rate of 0.1 Gbps, a peak data rate of 20 Gbps, and an end-to-end latency of 1 ms. 5G also supports high mobility of 500 km/h, a connection density of one million devices per square kilometer, an area traffic capacity of 10 Mbps per square meter, and is three times more spectrum-efficient and one hundred times more energy-efficient than 4G wireless communication systems. To achieve these goals, 5G incorporates several technologies such as massive multiple-input multiple-output (MIMO), millimeter wave (mmWave), and ultra-dense network (UDN) [2], [3].

Despite its capabilities, 5G may not be sufficient to meet all future demands beyond 2030. As a result, researchers are now focusing on developing 6G wireless communication networks. 6G will need to address additional requirements such as high phase synchronization accuracy and precision timing, in addition to offering close to 100% global coverage, high location precision, and millisecond update rates to meet user experience demands. While 5G networks have limitations in terms of coverage and are unable to effectively serve rural areas such as villages and highways, this restricts the use of certain applications such as driverless cars [4].

In addition, there are several other limitations of 5G networks, including, first: limited range: 5G networks operate at higher frequencies, which have shorter wavelengths and limited range. Second, significant infrastructure modifications, such as the construction of new base stations, fiber optic cables, and other equipment, are necessary for the deployment of demanding 5G networks [5]. Third, security concerns, 5G networks may introduce new security risks, particularly as more devices become connected to the network.

Light Fidelity (Li-Fi) technology builds upon Visible Light Communication (VLC) [6] to create fully networked wireless systems. This high-speed network was first introduced by German physicist Professor Harald Haas [6] and uses visible light for data transmission, with Light Emitting Diodes (LEDs) as transmitters and photodiodes (PDs) as receivers. Li-Fi has now become an integral part of 5G technology.

There is a need to develop the current wireless network, especially data rate, to be able to accommodate the huge demand on the network connections due to the increase of smart services based such as Internet of Everything (IoE). Although many IoE-based services could be supported by 5G networks, they are not sufficient to address all of the needs of emerging smart applications. As a result, the necessity for developing 6G wireless communication technologies is growing to alleviate the significant drawbacks of the current 5G networks.

Integrating artificial intelligence (AI) into 6G networks will provide solutions to highly complex issues related to network efficiency. Researchers [7] are exploring new technologies such as Li-Fi, quantum and THz communications to enhance the capabilities of 6G networks. The future requirements of 6G wireless communications will necessitate a wide range of applications, as shown in Fig. 1, that rely on data and serve a growing number of users. In contrast to current 5G networks, this paper focuses on recent trends and developments in 6G technology, including network requirements, critical enabling technologies, and specifically, Li-Fi technology.

Compared to 5G networks, 6G wireless communication networks are expected to offer higher spectral efficiency, cost-effectiveness, energy efficiency, and faster data rates (Tbps). 6G networks are also expected to support one hundred times more connection density, ten times lower latency, increased

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intelligence for full automation, location accuracy of less than 1 centimeter, time synchronization of less than 1 millisecond, and nearly 100% coverage. To achieve these goals, new air interface and transmission technologies are needed, including new waveforms, access mechanisms, multi-antenna technologies, and channel coding methods. These approaches need to be properly integrated to achieve high energy and spectrum efficiency [7]. Additionally, new network architectures will be required in the interim.

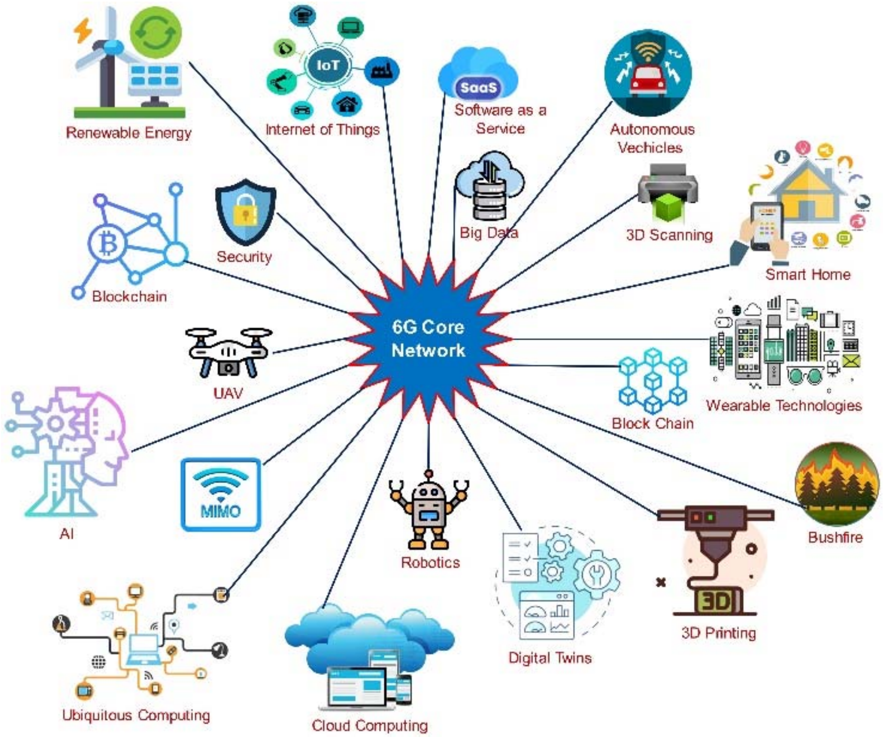

Fig. 1 Predicted 6G based applications

The organization of this paper is as follows: Section II will introduce related surveys, while Section III will present a spectrum for 6G. Section IV will focus on Li-Fi technology, and Section V will discuss its applications. Finally, the paper will conclude.

II. Related Surveys

Numerous studies have outlined the requirements and enabling technologies for 6G networks, including those presented in [8]-[10]. In particular, [9] proposes novel research directions for vital 6G technologies such as blockchain, AI, quantum communications, and machine learning (ML). Reference [10] envisions the use of ML and AI-based data in 6G networks, including the application of federated learning (FL), quantum learning (QL), and deep reinforcement learning (RL), which offer new opportunities for 6G communication networks, as discussed in [8], [11], [12]. Authors in [8] focus on traffic control, security, AI, and optimization in the radio interface of 6G networks.

In [13], the authors use blockchain technology to conduct a systematic review of privacy and security for 6G wireless networks. Meanwhile, [14] provides an in-depth investigation into the role of 6G in supporting Internet of Things (IoT) applications in various fields, including industries, healthcare, autonomous vehicles, and satellite communication. In [15], the authors focus on end-to-end communication optimization and network access for 6G networks, using ML to ensure quality of experience (QoE) and quality of service (QoS). Reference [16] proposes the use of unmanned aerial vehicles (UAVs) and blockchain-based UAV communication in 6G networks. However, only a few researchers are currently focusing on Li-Fi for 6G networks, as discussed in [17] and [18].

Several technologies currently used in 5G networks are expected to be further developed for 6G, including massive MIMO [19] and dense networks [20]. Furthermore, the potential improvements in waveform, modulation, and multiple access schemes for the MAC (medium access control) and PHY (physical) layers [21] will be significant contributions to the development of 6G networks.

This paper will showcase Li-Fi technology as a crucial component for achieving higher data rates of terabits per second (Tbps) in 6G networks. The paper will also highlight the advantages of this technology and its wide range of applications.

III. New Spectrum for 6G

Numerous research initiatives on 6G technology are already underway, exploring potential future needs and addressing the limitations of 5G. The development of 5G and its identified weaknesses will inform the design of 6G networks. One of the main challenges is to find a new spectrum and higher bandwidth, which will be in high demand for inter-vehicle communications in driverless vehicles and the IoT. This section will discuss some potential enabling technologies for 6G.

Millimeter-wave (mmWave) technology using new spectra with much higher frequencies (18-100 GHz) [22] may enable much wider channel bandwidth, which is needed to handle the increased data rate requirements for 6G networks. The TeraHertz portion of the spectrum may also be accessed using mmWave technology, which is expected to be further developed. Unlike 5G, 6G networks will use higher frequencies to achieve significantly faster sampling rates, higher data rates, and better throughput. The use of mmWave technology with wavelengths shorter than one millimeter and frequency selectivity to calculate relative electromagnetic absorption rates is expected to enhance wireless sensing technology [1]. While mmWave technology can achieve Gbps-level transmission rates in 5G, higher transmission rates of Tbps will be required for applications such as virtual reality (VR), high-quality 3D video, and a mix of VR and augmented reality (AR). The THz and optical frequency bands have great potential to meet the demands of 6G networks [5].

THz frequency situated between mmWave and infrared frequencies and is an important alternative for achieving Tbps communication rates with ultra-large communication bandwidth. Due to its high frequency, THz has millimeter-level and sub-millimeter-level wavelengths, making it appropriate for small handheld or wearable devices that needs high-precision positioning, high-resolution 3D imaging, and mass spectrometry analysis for materials. Unlike optical cameras, THz can penetrate certain obstacles, enabling high-precision imaging and all-weather sensing with enhanced privacy protection. THz bands can be used in various daily life and production scenarios, including non-invasive health monitoring, food safety checks, defect detection in high-precision manufacturing, pollution monitoring, and machine vision support [23], [24]. However, THz has certain limitations that may make it less suitable for upcoming networks.

Optical wireless communications (OWCs) [25] play a crucial role in device-to-access and network-to-backhaul connectivity in 6G networks. Established OWC technologies, such as VLC [26], free space optical [27], and Li-Fi [6], have been widely used in vehicle-to-everything technology, inter-satellite communication, virtual and augmented reality (VAR), underwater communication, and indoor and outdoor communications. These technologies will be employed even more in 6G networks, both in terrestrial and satellite communication systems, with the help of the necessary bandwidth.

VLC services with extremely high data rates of up to 100 Gbps can be achieved through differential wavelength division multiplexing, and future micro-LED arrays can be parallelized to further increase data rates to meet 6G standards. Fig. 2 shows that the combined visible light and infrared spectrum is approximately 2,600 times larger than the total radio frequency (RF) spectrum at 300 GHz. The infrared (IR) and visible light spectra are unregulated and offer a bandwidth of 780 THz [28].

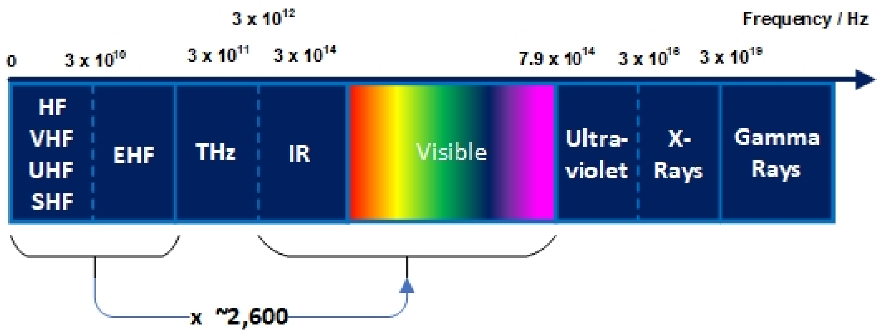

Fig. 2 New unregulated spectrum

IV. Li-Fi Technology

Li-Fi is an OWC technology that uses VLC and is expected to be a key component of 6G networks. Li-Fi uses LEDs to transmit optical signals that are received by PDs. LEDs are optical devices that can convert electrical signals to optical signals, and vice versa. Unlike the crowded and strictly regulated RF spectrum, Li-Fi is unregulated and has the potential to significantly enhance physical layer security. In contrast to terahertz communications, which typically operate at frequencies of 200 GHz to 10 THz, photonic systems and commercial transmitters and receivers for Li-Fi are already in use [18]. Li-Fi offers the potential for low-cost, short-range, multi-Gbps data rate transmission using approximately 300 THz of visible light spectrum [29], [30]. Additionally, Li-Fi leverages the indoor lighting infrastructure, which is designed to be small, safe, and environmentally friendly [31].

Orthogonal frequency division multiplexing (OFDM) is a widely used technique in both wired and wireless communication to increase data rates. In OFDM, the frequency range is divided into sub-bands, which helps overcome inter-symbol interference (ISI) in a dispersive channel [32]. OFDM has also been successfully used as a modulation system in VLC to address the limited bandwidth of LEDs [29]. Implementation of OFDM in VLC, known as optical OFDM (O-OFDM), significantly increases the data rate, which is highly in demand in new 5G networks and applications such as smart cities [33] and other potential applications [34]. In VLC, the communication mode is set as an intensity modulation/direct detection (IM/DD) wireless optical system, in which the transmission is achieved by controlling the optical signal of the

LED with respect to the input information signal, while detection is performed at the receiver using PDs. This system is easy to implement and provides the dual functions of illumination and communication [29], [35].

Despite its advantages, OFDM has a major drawback in the peak-to-average power ratio (PAPR) of the transmitted signal, which causes the LED to operate inefficiently and non-linearly. To prevent clipping and distortion, the optical signal must fit within the LED's limited dynamic range. If the PAPR exceeds the acceptable range, the signal may be outside the LED's dynamic range, leading to increased clipping distortion [36], [37].

In standard OFDM, the transmitted signal must be bipolar and complex, which is not suitable for driving LEDs in an IM/DD optical wireless system. Therefore, O-OFDM signals designed for IM/DD systems must be real and non-negative. This is achieved by using Hermitian symmetry in the OFDM symbol structure, resulting in a real-valued signal after the inverse fast Fourier transform (IFFT) process. VLC employs several types of O-OFDM schemes, such as Asymmetrically Clipped Optical OFDM (ACO-OFDM) [38], direct current optical OFDM (DCO-OFDM) [39], and their hybrid and non-hybrid variants. In DCO-OFDM, a DC-bias is introduced to the time-domain OFDM symbol after the IFFT process to remove all negative signal values. Any remaining negative signal is clipped at this point, since OFDM symbols have a high PAPR [40]. A higher level of DC-bias is usually needed to remove all remaining negative peaks. When a low bias is used, the clipping noise effect becomes dominant, and the error rate increases, since both even and odd sub-carriers contain data symbols.

In DCO-OFDM, clipping noise affects both even and odd sub-carriers, requiring a substantial DC-bias to make the OFDM signal positive. However, this leads to inefficiencies due to the need for large optical power [41], [42]. The effects of varying the DC-bias on the performance of DCO-OFDM signal have been analyzed in [43] through simulations of O-OFDM signals developed with M-ary quadrature amplitude modulation (QAM) schemes. In [37], a novel two-step peak clipping (TSPC) scheme has been introduced to mitigate PAPR in clipped and pilot-aided optical OFDM signals.

Compared to the terahertz spectrum (0.2 THz - 10 THz), one of the main advantages of using infrared and visible spectra to develop future wireless networks is that current technology can produce strong optical transmitters and receivers. Optical fiber connections operate in the range of 1260 to 1675 nm in the infrared spectrum, allowing OWCs to leverage advances and improvements in that area. VCSELs (vertical cavity surface-emitting lasers) can emit light between 800 nm and 1000 nm, have a large electrical bandwidth of up to 50 GHz, and are simple to fabricate. There are also many options for visible light sources. While the phosphor used to convert blue light to white light has a slow frequency response, causing problems for standard white LEDs, it is not required for red, green, and blue (RGB) LEDs, which also allow for wavelength division multiplexing (WDM) to enhance transmission linearity. Micro LEDs, while small, have optical output levels of several milli-watts [17].

According to the 6G blueprint, Li-Fi, which is a bidirectional, fully networked wireless solution based on VLC, is a crucial element. The high-speed and secure connectivity provided by Li-Fi enables extreme cell densification in indoor, vehicular, and underwater environments due to the beamforming and close range of light signals. However, the available bandwidth in Li-Fi networks is limited by the modulation bandwidth of the transmitting LEDs and their reliance on line-of-sight (LoS), which can cause link blockage and signal quality issues due to random receiver orientation. MIMO systems offer a promising solution to overcome these limitations and increase the capacity and diversity gains of Li-Fi. However, there is a risk of performance issues due to the close spatial sub-channel correlation [18].

The primary objective of intelligent Li-Fi systems is to enhance transceiver performance in the presence of unpredictable and uncontrollable channel conditions. Intelligent Li-Fi can automatically and efficiently adapt its operation to enable ubiquitous communication that is resilient to unfavorable probabilistic components, thereby utilizing the maximum signal available in the environment. To establish intelligent Li-Fi as a new frontier for 6G wireless networks, the paper [18] proposes a new perspective on the potential role that reconfigurable intelligent surfaces (RISs) can play in this regard. Compared to terahertz (THz) technology, Li-Fi has overcome all the challenges associated with 6G, such as severe atmospheric losses at THz frequencies and diffraction limits compared to RIS in intelligent Li-Fi, and LoS issues by employing OFDM-based IM/DD, which increases the data rate with the achieved signal-to-noise ratio (SNR). Moreover, Li-Fi does not interfere with sunlight, has no perceived flicker, and can operate with very low power or dimmed light [28], making it comparable to systems that use massive MIMO. An optical phased array can serve a large number of wireless devices by splitting the original beam into multiple users at various locations with configurable power allocations [7].

V. Li-Fi Applications

The optical spectrum offers an opportunity to develop next-generation communication systems that are fast, secure, reliable, environmentally friendly, and efficient. The available optical bandwidth is three times larger than the accessible spectrum resources in the RF band [44]. As a result, Li-Fi has a wide range of applications. In the following section, we will discuss some of these applications based on their demand in daily life.

A. Lighting

Li-Fi hotspots can be created using any light source, whether indoors or outdoors, such as room lights or streetlights. This enables homes, offices, businesses, healthcare facilities, airplanes, factories, streets, and cars to be connected to the internet using VLC technology based on Li-Fi. Additionally, banners and public signs can serve as hotspots and be utilized for various Li-Fi applications. Sensor technology can also be incorporated into lights for data management [45], [46].

B. Transportation

Transportation is a promising area for integrating Li-Fi, including vehicle-to-person communication (V2P) [47], vehicle-to-vehicle communication (V2V) [48], vehicle-to-network communication (V2N), and vehicle-to-infrastructure communication (V2I) [46]. Due to its ability for real-time communication, Li-Fi is particularly useful for driver-vehicle connections, where car headlights can be utilized for information sharing. Additionally, Li-Fi has significant potential for crash avoidance and traffic control, which can be achieved through traffic signals. This could reduce the frequency of injuries and pollution, especially in high-density areas. Since Li-Fi has no interference with other wireless technologies such as RF, it is highly safe and accurate [49]. Li-Fi can prevent interference with other wireless technologies in critical locations such as operating rooms, aircraft, and oil and petrochemical facilities, which opens up new opportunities compared to other electromagnetic radiation technologies [50].

C. Location

Location detection with high accuracy is another application of Li-Fi, which is utilized to process positional data. Li-Fi technology provides indoor positioning information with an accuracy of up to ten centimeters, which is suitable for navigation and user face recognition [51]. Li-Fi can also determine the location of users [45]. For example, when positional data are obtained through Li-Fi, the access point sends the user's positioning information to the main server. The main server then uses this information to generate a map of the user's location [52].

D. Industrial Environment

In industrial settings, such as automobile factories, the intensity, complexity of robots, and connections between devices and applications require proper delivery of data. In this scenario, Li-Fi can provide wireless data sharing with real-time and high-speed data rates to meet industrial application needs. This offers advantages such as reliability and high security without compromising wireless connectivity. This is mainly due to Li-Fi's exceptional data transfer and efficient connectivity, which enables automation of the production process. These features make Li-Fi a significant factor in business operations. Li-Fi is recognized as a crucial participant in the Industry 4.0 environment and has the potential to influence the importance of the upcoming industrial revolution [53], [54].

E. Educational System

Li-Fi is the fastest and most advanced internet connectivity technology, and performs exceptionally well in a variety of applications, including education. This makes Li-Fi the most cutting-edge internet networking infrastructure that provides the best internet connection. In corporate and educational settings, it can be a strong competitor to Wi-Fi. Therefore, it can be considered as one of the best frameworks for use in universities, conference centers, classrooms, testing facilities, and laboratories [55], [56].

F. Sound Communication

A secret Li-Fi application that uses a sound system to communicate is also available. Despite being less researched compared to other applications, sound system applications are important for integrating Li-Fi and thus warrant discussion. According to the authors of [46], pulse width modulation (PWM) can be utilized to transmit audio signals using different colors of LEDs [57].

VI. Conclusion

This paper has reviewed and demonstrated that Li-Fi technology is a crucial component for enabling 6G networks. It possesses outstanding features and has vast applications that make it a primary contender among emerging technologies. Although 6G networks do not yet exist and are only in the research phase, with requirements set by the International Telecommunication Union (ITU), some businesses have begun envisioning cutting-edge wireless use cases with 6G technology. A comparison between 5G and 6G networks is also provided.

Li-Fi technology is a key element of 6G due to its significant benefits, including the availability of a free spectrum, unlimited bandwidth, ease of setup, and simple architecture. In addition to visible light, infrared light is also used in Li-Fi. Currently, Li-Fi system architectures can achieve aggregate data rates of 1 Tbps with significantly improved user experience and security. Furthermore, Li-Fi technology's spectrum has been compared to other newly available spectra in terms of limitations and capabilities.

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