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From WI-FI to LI-FI: a comprehensive review of integration strategies

***Abstract**. Li-Fi, also known as light fidelity, is a promising technology for the wireless communication sector in the future. Similar to Wi-Fi, it is a fully networked and bidirectional technology that offers incredibly high speeds. However, there are some limitations associated with Li-Fi technology, such as its reliance online of sight between the transmitter and receiver, its susceptibility to interference from external light sources, and its short coverage area, particularly indoors. Therefore, to overcome these issues, proposed integrating Li-Fi with other hybrid wireless communication technologies. This article discusses the integration of Li-Fi with Wi-Fi and cellular networks in V2X (vehicle-to-everything) communication, satellite communication systems, and Industrial IoT (IIoT). In the future, as the speed of light is significantly faster than other transmission methods, Li-Fi technology has the potential to revolutionize data access speeds for devices.*

Streszczenie.** Li-Fi, znany również jako light fidelity, to obiecująca technologia dla sektora komunikacji bezprzewodowej przyszłości. Podobnie jak Wi-Fi, jest to w pełni sieciowa i dwukierunkowa technologia, która oferuje niewiarygodnie wysokie prędkości. Istnieją jednak pewne ograniczenia związane z technologią Li-Fi, takie jak zależność od linii wzroku między nadajnikiem a odbiornikiem, podatność na zakłócenia ze strony zewnętrznych źródeł światła oraz krótki zasięg, szczególnie w pomieszczeniach. Dlatego, aby przezwyciężyć te problemy, zaproponowano integrację Li-Fi z innymi hybrydowymi technologiami komunikacji bezprzewodowej. W tym artykule omówiono integrację Li-Fi z Wi-Fi i sieciami komórkowymi w komunikacji V2X (vehicle-to-everything), systemach komunikacji satelitarnej i przemysłowym IoT (IIoT). W przyszłości, ponieważ prędkość światła będzie znacznie większa niż w przypadku innych metod transmisji, technologia Li-Fi może zrewolucjonizować prędkości dostępu do danych w pomieszczeniach.* (Od WI-FI do LI-FI: kompleksowy przegląd strategii integracyjnych***)

Keywords: light fidelity, wireless communication, hybrid, indoor.
Słowa kluczowe: wierność światła, komunikacja bezprzewodowa, hybrydowy, wewnętrzny.

Introduction

In today's world, transferring data from one place to another is one of the most crucial activities in our daily lives. However, when multiple devices or users connect to the current wireless network, internet connectivity can slow down due to high radio frequency (RF) interference. To tackle this problem, Li-Fi technology can be used as a solution. Li-Fi is a data transmission technology that uses LED light, which can vary in intensity faster than the human eye can follow, for high-speed data transmission [1]. This technology uses the light spectrum to transmit data through LED light instead of Gigahertz radio waves for data transfer. With the help of visible light communication spectrum, Li-Fi is much faster and has no side effects on humans [2].

Integrating Li-Fi with other wireless communication technologies can bring many benefits such as increased capacity, coverage, reliability, reduced congestion, and increased security. One approach to integrating Li-Fi and Wi-Fi is to use Li-Fi as a complementary technology to Wi-Fi, where Li-Fi is used in situations where Wi-Fi is not feasible or unavailable. For instance, Li-Fi could be used in areas with high electromagnetic interference density, which can interfere with Wi-Fi signals. Another approach to integrating Li-Fi and Wi-Fi is to use them together in a hybrid system where both technologies are used to transmit data. This can allow for increased capacity, coverage, reliability, and robustness of the communication system.

There is also ongoing research on integrating Li-Fi with cellular networks, such as 5G. One approach is to use Li-Fi as a way to offload data traffic from the cellular network, which can help to reduce congestion and improve network performance. Another approach is to use Li-Fi to provide coverage in areas where it is challenging to deploy cellular infrastructure, such as inside buildings or remote locations. Additionally, Li-Fi can be integrated with various wireless communication systems such as Hybrid Li-Fi/Wi-Fi networks, Li-Fi in cellular networks, Li-Fi in satellite communication systems, Li-Fi in V2X (vehicle-to-everything) communication, and Li-Fi in Industrial IoT (IIoT). These integrations can improve the performance, coverage, reliability, and security of communication systems.

Overview of Li-Fi technology

Li-Fi is a wireless communication system that uses illumination to transmit data. It transmits data through an LED light bulb that varies in intensity faster than the human eye can follow. Li-Fi offers new capabilities to current and future services, applications, and end users.

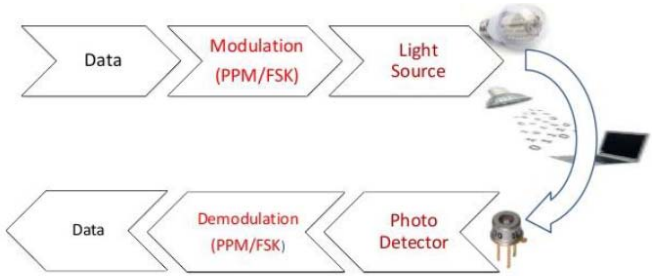

Fig 1. Block Diagram of Li-Fi [3]

The block diagram above illustrates the process of data transmission from the transmitter to the receiver. The data is first modulated (PPM/FSK) to the light source and then transmitted via light to a photo detector through the transmission medium. The data is then demodulated (PPM/FSK) in the receiver part. The LED light source's intensity is modulated by the data from the internet and local network, which is undetectable to the human eye. The photodetector receives the signal, which is converted back into a data stream and sent to the client. The client can communicate through its own LED output or over the existing network.

Li-Fi offers several features, including high-speed communication for downloading movies, music, and games in a short time. It also removes limitations for Wi-Fi users, as the capacity with light is 10,000 times wider than radio waves [3]. It is more efficient because LED lights consume less energy. The availability of LED lights worldwide makes it easier to transmit data. Li-Fi offers high security as light waves are more secure than electric waves. Furthermore, it is safe because unlike radio frequencies, Li-Fi cannot penetrate the human body.

Integration with Wi-Fi

There are several ways to integrate Li-Fi and Wi-Fi for wireless connectivity. These include utilizing them in complementary or hybrid systems, as well as using Li-Fi to offload data traffic from Wi-Fi networks [4]. Integration can be approached in a few ways, such as complementary use, hybrid systems, and data traffic offloading. Complementary use refers to using Li-Fi in situations where Wi-Fi is not feasible or unavailable, such as areas with high electromagnetic interference. In a hybrid system, both technologies can be used together to transmit data, resulting in increased capacity, coverage, and communication system reliability [5]. Lastly, Li-Fi can be used to offload data traffic from Wi-Fi networks, which can help reduce congestion and improve overall network performance.

Integration with cellular network

Generally, integration the use of Li-Fi with cellular to complement or augment cellular networks, such as 5G, and the potential benefits of this integration, such as increased coverage and reduced congestion [6]. There are several ways in which Li-Fi technology can be integrated with cellular networks. Firstly, complementary use. Actually, Li-Fi can be used in areas where it is difficult to deploy cellular infrastructure, such as inside buildings or in remote locations. This can provide additional coverage and capacity for the cellular network. Secondly, offloading data traffic. Li-Fi system can be used to offload data traffic from the cellular network, which can help to reduce congestion and improve network performance. Thirdly, by using the hybrid systems. Integration between Li-Fi and cellular networks can be used together in a hybrid system, where both technologies are used to transmit data. This can allow for increased capacity and coverage, as well as increased reliability and robustness of the communication system. Fourthly, Internet of Things (IoT) applications with is Li-Fi can be used to connect IoT devices to the cellular network, allowing for the transmission of large amounts of data from these devices.

Li-Fi in satellite communication systems

The incorporation of Li-Fi into satellite communication systems holds the potential for delivering high-speed internet access to areas that are remote or difficult to reach, like airplanes, ships, and other vehicles that are beyond the range of traditional wireless networks and remote land locations. One approach to integrate Li-Fi with satellite communication systems is through the utilization of a satellite equipped with a Li-Fi transceiver, enabling the satellite to transmit and receive data via Li-Fi technology and communicate with ground or airborne devices. The satellite would then forward the data to other satellites or to a ground station for further dissemination.

Another method to integrate Li-Fi with satellite communication systems is through the utilization of a ground-based Li-Fi transceiver that can communicate with a satellite, allowing for the transmission of data from the ground to the satellite, which can then be forwarded to other satellites or a ground station for further dissemination [7]. To makes either of these integration approaches possible, Li-Fi technology must be modified to function at longer distances and higher speeds than current Li-Fi technology and transmit data through the atmosphere. There are several technical challenges that must be addressed to make this integration a reality, such as devising a way to transmit Li-Fi signals through the atmosphere without scattering or absorption and developing a method to connect Li-Fi devices to satellite networks.

Li-Fi in V2X (vehicle-to-everything) communication

Li-Fi technology has potential applications as a communication method for V2X (vehicle-to-everything) systems. In a study published in the IEEE Transactions on Intelligent Transportation Systems in 2019 [8], researchers proposed a Li-Fi-based V2X communication system that can support high-bandwidth, low-latency, and secure communication between vehicles and other entities such as infrastructure and other vehicles. The study demonstrated that the proposed system could support various V2X applications, including advanced driver assistance systems (ADAS), autonomous driving, and traffic management.

Another study published in the IEEE Access in 2018 [9] presented a Li-Fi-based V2V (vehicle-to-vehicle) communication system that can support high-speed, secure, and low-latency communication between vehicles. The research showed that the proposed system can support various V2V applications, such as collision avoidance, traffic management, and entertainment services. Additionally, a study published in the IEEE Internet of Things Journal in 2019 [10] proposed a Li-Fi-based V2I (vehicle-to-infrastructure) communication system that can support high-speed, secure, and low-latency communication between vehicles and infrastructure, such as traffic lights, road signs, and charging stations. The study demonstrated that the proposed system can support various V2I applications, including real-time traffic management, parking management, and energy-efficient charging.

Li-Fi in Industrial IoT

Li-Fi technology has the potential to provide high-speed, secure, and reliable communication for industrial applications in the Industrial Internet of Things (IIoT). This technology can be used to connect industrial devices, such as sensors, actuators, and robots, to a network for data collection and control. There are two ways to integrate Li-Fi in IIoT. The first is to use Li-Fi as the primary communication method for industrial devices, which provides high-speed data transfer for real-time control and monitoring of industrial processes [11]. The second is to use Li-Fi as a backup or complementary communication method to existing technologies such as Wi-Fi or cellular networks, providing an additional layer of security and reliability for industrial 4.0 communication systems [12].

Li-Fi is also useful in areas where traditional wireless technologies are not suitable, such as environments with high levels of electromagnetic interference (EMI) or radio frequency interference (RFI) [13]. However, before Li-Fi can be widely adopted for IIoT applications, there are still some technical challenges to overcome. For example, Li-Fi signals can be easily interfered with by other light sources, such as sunlight, or by other wireless signals, such as Wi-Fi. Additionally, Li-Fi requires a line of sight between the transmitter and receiver, which can be difficult to achieve in certain industrial environments [14].

Challenges and Limitations

This project faces numerous obstacles and constraints in integrating Li-Fi with Wi-Fi. Firstly, Li-Fi requires specialized hardware such as LEDs and photodetectors, which could be a hurdle for widespread adoption of the technology. Secondly, interference from other light sources could disrupt Li-Fi signals. Thirdly, Li-Fi has a limited range compared to other wireless technologies, which could be a challenge for providing coverage over large areas. Fourthly, integrating Li-Fi with Wi-Fi could be difficult due to the use of different technologies to transmit data. Fifthly, regulatory challenges may arise due to the visible light spectrum already being regulated for other purposes.

Similarly, integrating Li-Fi with cellular networks also presents challenges and limitations. Firstly, specialized hardware is required for Li-Fi technology, which could hinder its widespread adoption. Secondly, interference from other light sources could disrupt Li-Fi signals. Thirdly, Li-Fi has a limited range compared to other wireless technologies, which could be a challenge for providing coverage over large areas. Fourthly, implementing Li-Fi technology could be costlier compared to other wireless technologies. Fifthly, regulatory challenges may arise due to the visible light spectrum already being regulated for other purposes.

Incorporating Li-Fi technology into V2X communication systems also poses several challenges that need to be overcome. The main challenge is the need for a clear line of sight between the transmitter and receiver, which could be difficult to achieve in a vehicle-to-vehicle or vehicle-to-infrastructure communication system. Interference from other light sources or wireless signals can also make it difficult to maintain a stable and reliable communication link. Developing new communication protocols and techniques to adapt to changes in distance and alignment, as well as standardization, are necessary for successful integration of Li-Fi in V2X communication systems.

Moreover, integrating Li-Fi in Industrial Internet of Things (IIoT) presents challenges that need to be addressed. Interference from other light sources or wireless signals, line of sight requirement, security, power consumption, standardization, and cost are all challenges that need to be overcome to ensure the successful integration of Li-Fi in IIoT. Overall, despite the challenges and limitations, ongoing research aims to overcome these obstacles and make Li-Fi a more viable option for wireless communication with other technologies.

Future prospects

Li-Fi technology has the potential to integrate with other wireless technologies, such as cellular networks, to create a more efficient communication system. This could be especially useful in indoor environments where RF signals may be weak or disrupted, while cellular networks can be used for outdoor communication. Furthermore, Li-Fi can be combined with satellite communication systems to provide high-speed internet access to remote and inaccessible areas such as planes, ships, and rural locations. However, this integration would require modifications to the Li-Fi technology to operate at longer distances and higher speeds than current technology and to be able to transmit data through the medium.

Li-Fi technology can also be used in several ways as a communication method for the Internet of Things (IoT). Firstly, it can provide faster internet speeds than traditional Wi-Fi, which could benefit IoT devices that require high-bandwidth communication such as video streaming or large data transfers. Secondly, Li-Fi signals are more secure than traditional Wi-Fi signals since they are less likely to penetrate walls and other obstacles, which could be advantageous for IoT devices that handle sensitive information or operate in secure environments. Thirdly, Li-Fi can support more devices per area than traditional Wi-Fi, making it ideal for IoT devices in crowded areas. Fourthly, it can communicate with low-power IoT devices that require long battery life, such as sensors and actuators. Fifthly, Li-Fi technology can be integrated into existing LED lighting systems, making it a cost-effective option. Finally, Li-Fi communication is more energy-efficient than Wi-Fi since it only uses the light source when data transmission occurs.

Nevertheless, Li-Fi technology still faces some technical challenges. For example, Li-Fi signals can be obstructed by walls and furniture, reducing the range of communication. Additionally, Li-Fi technology is still relatively new and may not be as widely supported as traditional Wi-Fi in terms of device compatibility. To make Li-Fi a viable option for IoT devices, researchers and industry professionals are actively working on solutions and standards to overcome these challenges.

Conclusion

In conclusion, the integration of Li-Fi technology with other wireless communication systems such as satellite communication systems and Industrial Internet of Things (IIoT) has the potential to offer fast, secure, and dependable communication. Nonetheless, there are a few challenges that need to be addressed before Li-Fi can be widely adopted for these applications. The primary challenges in integrating Li-Fi in satellite communication systems are the need for line of sight between the transmitter and receiver, interference from other light sources and wireless signals, power consumption, range, security, standardization, and cost. Similarly, in Industrial Internet of Things (IIoT) applications, Li-Fi faces challenges such as interference, line of sight requirement, security, power consumption, and cost.

Overall, while Li-Fi has the potential to provide high-speed and secure communication in various wireless communication systems, it's essential to note that Li-Fi technology is still in its early stages of development, and there are several technical challenges that need to be overcome before it can be widely adopted. Nevertheless, the potential benefits of Li-Fi make it an exciting area of research and development for the future of wireless communication. It has the potential to significantly impact the future of wireless communication by reducing RF interference and using the visible light spectrum, which improves overall communication reliability. As Li-Fi can be integrated into LED lighting systems, it can be implemented at a relatively low cost and is more energy-efficient than Wi-Fi, which uses radio frequency (RF) all the time [15].

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