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Li-Fi Technology: Revolutionising High-Speed Wireless Communication through Light

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Abstract—This paper discusses performance, lifespan, and the prospect of using LEDs as a more reliable source of light for residential and commercial applications, in place of a traditional light bulb, compact fluorescents, or traditional incandescent bulbs. LEDs prove versatile with numerous applications: VLC systems; for example, advancements where light is used for dual purposes: illumination and data transmission. VLC, especially Li-Fi, as an alternative to conventional RF-based wireless communication systems may become important where RF-based communications are of limited scope, especially in in-flight data transmission, underwater network, and transportation systems.

We propose a prototype Li-Fi system for data and file transfer by making use of UART serial communication to enable visible light-based data exchange between devices. System A uses a PIC microcontroller with which the LED signals are managed, this providing a modulation of data at both the transmitting and receiving ends. Data is transmitted via visible light through LEDs while photodiodes capture and decode such signals at the receiving end. The PIC controller connects to PCs for processing of data, and serial ports on android devices allow compatibility and portability of the device in many applications.

Keywords—Li-Fi, VLC, LED, UART, PIC Microcontroller, Optical Wireless Communication, Underwater Optical Communication, UAV, Wireless Sensor Networks.

I. INTRODUCTION

The global wireless keeps growing, exceeding 5 billion mobile phone users and above 4 million cellular base stations; yet, increasing demand for data constrains the already limited radio frequency (RF) spectrum critical to the scalability, reliability, and security of wireless communication. Li-Fi technology, a system of carrying data through visible light, seems very promising because its speeds would be higher; the levels of flexibility will increase as well, and it's also more energy-efficient. Unlike Wi-Fi, it deploys the visible spectrum because we have less congestion in the RF spectrum, therefore less interference.

Li-Fi technology links VLC with LED transmitters and photodiode or image sensor receivers, and it enables high-speed data transmission which also assures high security at the same time maintaining regular lighting functionality. Additionally, Li-Fi systems can be applied to location-based services, hence providing room for possibilities in navigation, targeted advertising, and asset tracking. Further, indoor optical wireless communication has exhibited

how LED lighting functions have been integrated with data transfer, providing a quite innovative means for environments where RF communication was previously limited.
The paper highlights the various advantages that Li-Fi provides, ranging from solving bandwidth and interference problems that are inextricably linked with Wi-Fi. A review of the available literature on Li-Fi is provided along with recommendations for future works, which positions Li-Fi as a giant leap towards high-speed secure and highly scalable wireless communication.

II. OVERVIEW OF LI-FI TECHNOLOGY

Li-Fi is an emerging light wave-based wireless communication technology by using the light waves emitted from LEDs to carry data. It is faster, a more secure, and more flexible alternative to RF based systems like Wi-Fi. Since the RF spectrum is getting progressively congested with the deployment of mobile and wireless devices all over the world, existing networks face serious issues related to scalability, reliability, and security. Unlike RF, Li-Fi applies VLC application: information is encoded to modify the signals on LED light, interpreted by the photodiodes and image sensors, and data transfer can take place much faster than that across Wi-Fi without emitting RF. Li-Fi is also more secure because light signals cannot cross walls, and can be fully integrated with LED lighting to convey data efficiently using energy. This dual-purpose technology shows hopeful promise for indoor navigation, asset tracking, high-speed internet connectivity, and environments in which RF communication is limited, including in-flight data systems and underwater communication. Despite its potential, Li-Fi still needs more research and development in terms of infrastructure, modulation techniques, and on-site integration with the existing wireless systems, hence holding a very important yet evolving solution for future wireless connectivity.

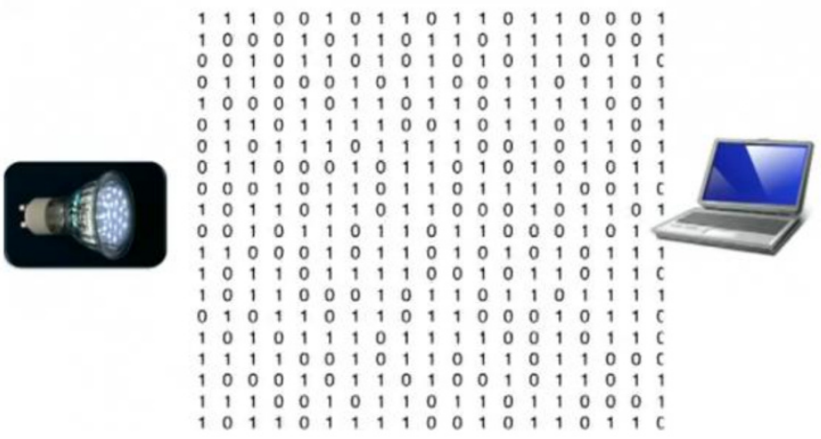

Fig. 1. Li-Fi transmission

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III. Li-Fi Light Design

Before Li-Fi light requires various LED bulbs and various wireless devices, including personal digital assistants (PDAs) and laptops. Li-Fi networks are interdependent, so they are complex.

The Basics of Li-Fi: Li-Fi technology uses bright LEDs that modulate light intensity at speeds far beyond human perception to enable fast binary data transmission. Modulation is managed by a controller that is connected to each LED.

Fundamentals of a Li-Fi Network:

Usually, a Li-Fi connection is a Li-Fi connection, i.e., LEDs are light modulated LEDs that encode binary data, The receiver photodetector detects changes in light intensity and decodes it, The system controller is in charge of modulation and data handling.

Design Importance: Li-Fi systems are very good; they can be modified for specific functions without sacrificing essential components. Streetlights can be used as both illumination sources and data transmitters in urban areas.

Li-Fi could transform wireless communication, enabling faster data transfer and improved data transfer across multiple applications.

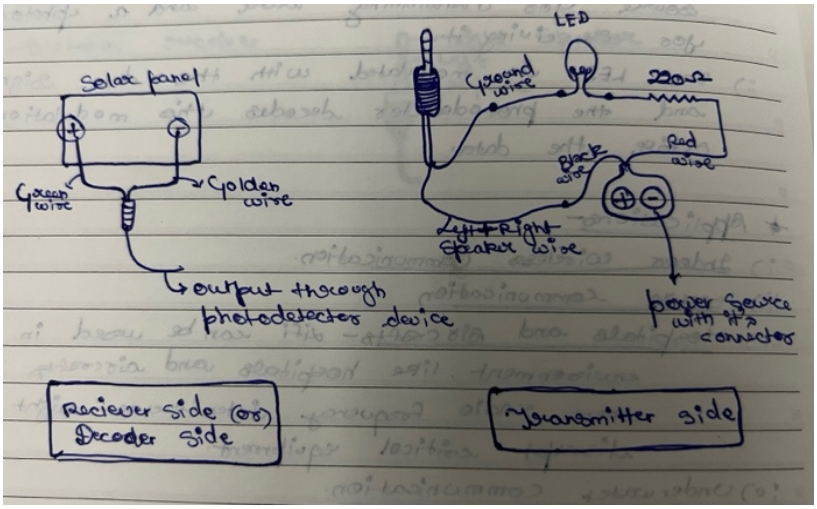

Fig. 2. Basic Circuit Design

IV. Implementation of Li-Fi

Li-Fi is a common use of white LED light bulbs as downlink transmitters. The usual way of illumination in these devices is through the use of a constant current. Li-Fi systems are fast and precise and can modulate optical output at high speeds. LED on, LED on, LED off (LED 0).

Li-Fi requires specific infrastructure, such as LED arrays and photodetectors. The network arrangement permits the transfer of data from a source to an LED and then to a photodetector

for decoding. Li-Fi has limitations, including line of sight, limitations of current technology, and cost of implementation. Li-Fi can transmit data at speeds of 1 Gbps over distances of 10 meters, according to research at the University of Edinburgh. Distance or other obstacles between the transmitter and receiver can affect the performance of a system.

This section delves into the difficulties associated with deploying Li-Fi and offers a look at some existing implementations, including some successful installations in educational institutions as well as commercial enterprises. A set of LEDs and a controller encrypts data into these light sources. The LEDs flicker, and the data is encoded, so there are many different things you can do to make them flicker faster. A set of LEDs can transmit data in unison, and the use of red, green, and blue LEDs can alter the light's frequency, with each LED color encoding a different data channel. The latest recommendations suggest a theoretical maximum speed of 10 Gbps, which would allow for the downloading of a complete high-definition movie in about 30 seconds.

V. PRINCIPLE OF LI-FI

Component LEDs are high brightness and are the basis of the Light Fidelity (Li-Fi) technology, which enables visible light communication via LEDs. Li-Fi is a new way to address the global shortage of wireless spectrum by using visible light for data transmission. VLC operates in the range of 400 THz (780 nm) to 800 THz (375 nm).

LEDs are getting cheaper, and the cost of these light sources is decreasing fast. A 60-watt LED light is expected to cost less than $10 in 2014 and $5 by 2020, as an illustration. White LEDs replace incandescent and fluorescent bulbs, making Li-Fi cheaper. LED lamps are around 100 lumens per watt (lm/W), and by 2025, it is expected to reach 200 lm/W, which is significantly more than incandescent bulbs (20 lm/W) and fluorescent lights (about 100 lm/W).

LED lamps have a very long life and a high luminous efficacy—40 times the typical incandescent life. In many countries, incandescent lamps are banned for being inefficient. The USA, EU, Japan, China, Russia, and Brazil have all phased out 100-watt incandescent lamps since late 2012 and have a goal of completely eliminating all incandescent bulbs by 2016.

Li-Fi can be used as a universal communication technology by integrating LED lighting into existing building infrastructure. Li-Fi has many advantages over traditional radio communication technologies like Wi-Fi and cellular networks. Communication over the full spectrum of visible light is largely dependent on frequencies well above 3 THz.

Li-Fi also provides security by preventing visible light from permeating thick materials like walls, thereby reducing the risk of unauthorized entry. Li-Fi is a promising and safe wireless communication technology; it's not harmful to the health of individuals exposed to the light, and the data transmission source is visible. LED lighting makes it easier to integrate communication features into existing infrastructure, paving the way for Li-Fi to become the standard for data transmission.

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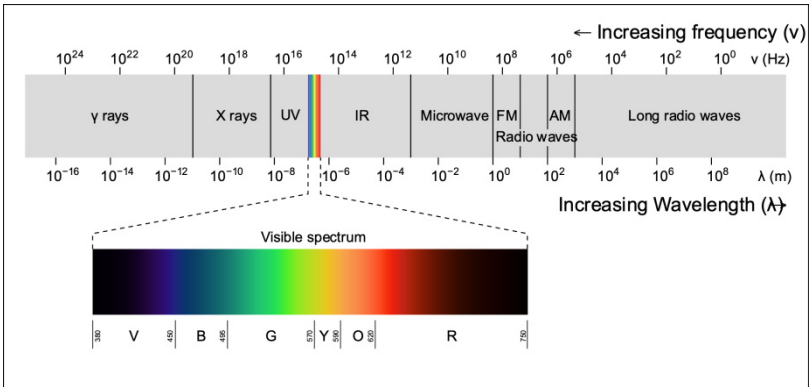

Fig. 3. Electromagnetic spectrum

VI. WORKING OF LI-FI

The lamp driver can get internet data when the LED is on and it turns it into light by a microchip. A photo detector retransmits the signal to a light-sensitive device, and it goes back to the original. Visible light communication is a technique of using fast pulses of light to wirelessly transmit information.

LED's illuminated efficiency is not subject to radio regulation law at this time. If all lights in your room could communicate with each other, creating a network of wireless networks to connect to the internet, what would be the best alternative to Wi-Fi? Wireless at home, office, university, 10 Gbps, on the move 100 Mbps, home wireless data network with a local cloud server as shown in Fig 4.

Fig 5**.** Li-Fi systems use a white LED with high brightness as the transmission source. A silicon photodiode that is good for receiving visible light with good sensitivity. By switching lights on and off, digital strings of different 1s and 0s can be generated.

Flickering the LED means that data can be encoded in the light to create a fresh data stream. The LEDs can be sent or sourced by adjusting the modulation of the data signal into the LED light. The LED flickers, and the human eye sees the same thing. High-speed LEDs can communicate at speeds over 100 Mbps using multiplexing techniques. An array of LEDs, with each LED transmitting a different data stream, allows parallel data transmission to be achieved and increases the VLC data rate.

The Li-Fi emitter system is composed of four main components, each of which is a high-intensity power amplifier circuit consisting of a bulb and RF circuit, a printed circuit board (PCB), and a PCB enclosure.

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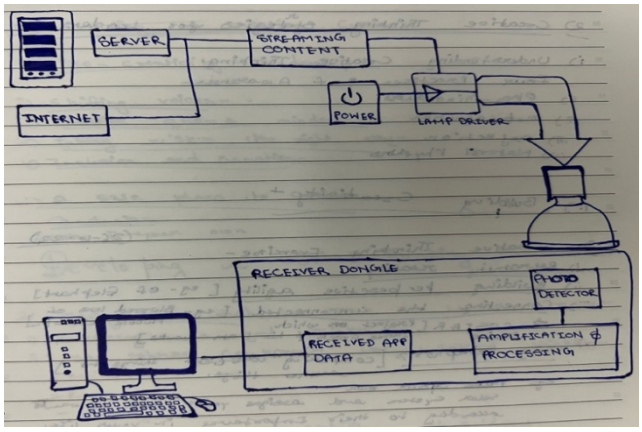

Fig. 4. Large Scale Application

Fig 5. The mechanical durability of the structure, which surpasses that of tungsten electrodes and glass to metal seals, is shown in Fig 5. A white LED with a bright white LED and a silicon photodiode serves as the communication input, and digitally controlled solid-state electronics make a very economical lamp family that can be arranged in different sizes. Digital strings of 1s and 0s can be generated by switching on and off a light source. Flickering the LED causes the light to flicker, and the data is encoded in the light to create a new stream. LED light and data signals can be used as communication mediums for better clarity.

The LED output looks unchanging to the human eye due to the fast flickering rate. High-speed LEDs with multiplexing can achieve data rates up to 100 Mbps. LED arrays can be used for parallel data transmission and can increase the VLC data rate, with each LED delivering a different data stream. VLC is the best lighting, even though there are other lighting devices like incandescent and fluorescent lamps.

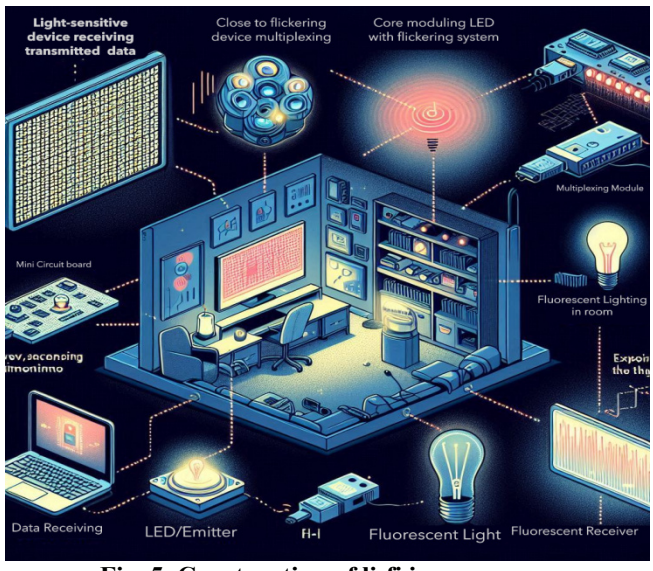

Fig. 5. Construction of li-fi in a room

VII. INTERNAL DESIGN OF LI-FI SYSTEMS

The Li-Fi systems are based on a range of factors, including the diameter and position of LED lamps. Depends on the number, size, and arrangement of LEDs in the lamp. Flat, circular with round tips, and adjustable shapes of lamps. Li-Fi uses LED types for specific purposes, including round tip LEDs and chip LEDs.

LED Size vs. Data Rate: LED size is closely linked to the data rate R in Li-Fi technology. Data rates can be varied across different sizes of LEDs. Micro LEDs can manage millions of light changes; standard LED bulbs can be turned into micro LEDs. Micro LEDs can get data rates of 3.5 Gbps and 10 Gbps. Micro LEDs allow parallel light streams and can transmit gigabit data. A microchip LED bulb can lead to internet and services with data rates up to 150 Mbps, providing high-speed internet speeds.

So the data rate R is inversely proportional to the LED's size. 5 mm, 3 mm, 1.8 mm, 1 mm, 1 m, 1 nm, respectively. Pixel LEDs 1 m, 1 nm are connected to the highest data rate.

Comparison of Data Rate and Number of LEDs: The data rate can be boosted by increasing the number of LEDs N in a lamp. If you have enough space inside the lamp, you can make it a LED to get the highest bit rate (bps). N is directly proportional to the data rate R.

Comparison of Data Rate and On/Off Switching of LEDs: LED light bulbs on/off produce binary numbers 1 and 0, with 1 on and 0 off. Micro LEDs allow high-speed data transmission by adjusting for millions of light intensity changes per second. Speedy on/off switching works at a rate that is faster than human understanding, enabling efficient data transmission for large amounts of data. Micro LEDs transmit data 1000 times faster than on-off switches, so you can get to a specific point faster. R is directly proportional to the on/off switching speed of the LED.

VIII. RECENT ADVANCEMENTS IN LI-FI

Li-Fi technology has evolved to provide faster and more flexible data transmission for communication and lighting applications.

Fast Data Transfer: Using common white light LEDs, researchers at the Heinrich Hertz Institute in Berlin, Germany, were able to attain data speeds of more than 500 megabytes per second. This invention demonstrates how contemporary lighting systems can now be used for both data transmission and illumination.

The Display Technology of Casio: Casio unveiled a new technology at the 2012 Consumer Electronics Show in Las Vegas that exchanges data using different screen light intensities. Li-Fi's promise as a practical data transmission technology is demonstrated by this technique, which works up to 10 meters away.

Li-Fi Alliance: The Li-Fi Consortium was established in October 2011 and is made up of businesses and organisations that collaborate to develop high-speed optical wireless networks. The collaboration wants to improve Li-Fi technology and get around restrictions on RF frequency. The group claims that theoretical rates of over 10 Gbps are possible, allowing for applications such as the 30-second download of a high-definition movie.

The Dedication of UTS Scotland to Real-World Applications: UTS Scotland is committed to bringing high-speed Li-Fi to the market, with a focus on real-world uses for this cutting-edge

technology. Their initiatives highlight how Li-Fi has the potential to revolutionise data transfer and increase wireless connectivity in a variety of domains and sectors.

IX. COMPARISON OF LI-FI AND WI-FI

Visible light communication technology, also known as Light Fidelity, makes wireless communication fast and easy. Its name is like Wi-Fi, which depends on radio frequency. Wi-Fi is a good wireless option for buildings, but Li-Fi is a better way to transmit data in confined spaces and reduce the impact of radio signal interference. The differences between these two technologies, which have been backed by recent discoveries and research, are the focus of this discussion.

The speed at which data is transmitted: Li-Fi has been shown to transmit data much faster than Wi-Fi. Utah's recent research has revealed that Li-Fi data rates surpass 10 Gbps, a remarkable advancement that enables high-definition films to be downloaded in just 30 seconds. IEEE 802.11n offers speeds of up to 150 Mbps in ideal conditions, but these speeds are often less than the theoretical speeds because of network congestion and interference.

Capacity: Light's bandwidth is 10,000 times greater than radio waves, so you can transmit more data at the same time. Li-Fi works on buildings already with pre-existing light sources, so you can use it without a huge cost increase.

Wi-Fi issues: What is the purpose of the following? Mobile devices and applications are moving at a high speed, so radio waves are limited, causing congestion and speed, What is the purpose of the second? Cell radio base stations use only 5 percent of the energy for data transmission and the rest is spent cooling systems, What is the purpose of the above-mentioned? Radio waves are a problem in limited environments like airplanes and petrochemical plants, The purpose of the program is to provide a platform for students to showcase their skills and knowledge. Radio waves can penetrate walls and spread infection by hammering holes, so it's a security concern.

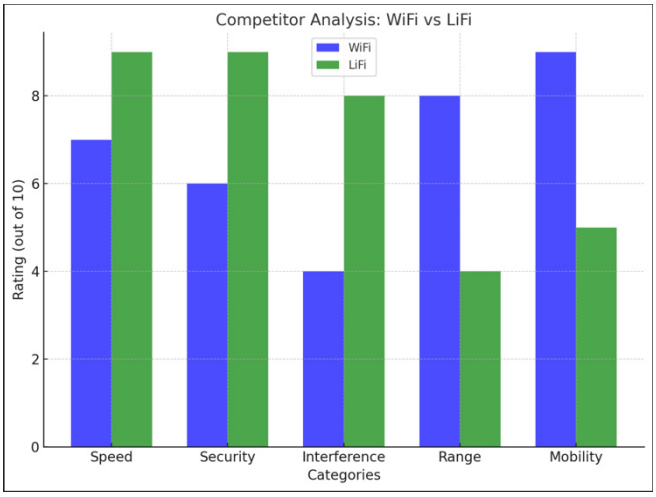

Fig. 6. Comprision between Wi-Fi vs Li-Fi

Technology	Latency	Throughput
Optical fiber	<1 ms	100 Gbps
FSO	<1 ms	40 Gbps
mmWave	<1 ms	10 Gbps
Microwave	<1 ms	1 Gbps

Fig. 7. EM waves throughput Representation

The positive aspects of Li-Fi: What is the purpose of the following? Li-Fi can harness signals from visible, ultraviolet, and infrared wavelengths, making it flexible for transmitting data, What is the purpose of the second? LED lighting is a very energy-efficient option that can reduce the operating costs of Li-Fi systems, What is the purpose of the above-mentioned? Millions of bulbs could be converted to Li-Fi compatible LEDs, which could make wireless internet access much easier, given the huge amount of bulbs already in use around the world, The purpose of the program is to provide a platform for students to showcase their skills and knowledge. Li-Fi is safer because it is hard to intercept signals, and there is no wall penetration in it.

Li-Fi is a bad idea. Li-Fi has its advantages, but it has its drawbacks: What is the purpose of the following? Light cannot penetrate walls or opaque materials, so there is no direct line of sight in the environment, What is the purpose of the second? Line of sight: to keep connectivity up, users must stay within the range of the light source, which can be a bit cumbersome compared to Wi-Fi omnipresence.

Recent developments in Li-Fi: Li-Fi has made a lot of progress.

X. APPLICATION OF LI-FI

Li-fi applications are a lot more powerful than li-fi. Li fi's high speed wireless communication using light is a prime example. Technology can solve the gaps in traditional wi-fi, especially in sensitive settings. Li-fi is a great way to use it, and it has potential for defence industry growth What is the purpose of the following:

The public internet: Street lamps can be li-fi integrated and turned into data transmission points. People can access the internet in public spaces without interference and limitations of radio waves thanks to this method. Li-fi networks allow cities to offer free and fast internet to both residents and visitors, reducing congestion on traditional networks.

The Second purpose of this is, System of education system:

Li-fi is available in classrooms and lecture halls and high speed internet is available. Implementing this could result in improved learning outcomes through real time data, interactive learning platforms, and effective communication between educators and students. Li-fi has been proven to significantly enhance the digital learning experience, with data rates exceeding 1 gbps.

The another purpose of this is, Medical related applications:

Wi-fi is often restricted in operating theatres, especially operating rooms, as it can cause interference with sensitive medical equipment. Li-fi is a practical choice, enabling healthcare professionals to connect and manage medical devices without Jeopardising patient safety. Li-fi could speed up data transmission in robotic surgeries and telemedicine, and ensure that vital medical equipment functions are always on.

What is the purpose of the fourth, Aircraft Synchronisation:

Planes now offer a limited range of internet services to passengers, often with high fees, and the use of wi-fi is prevalent, but it could potentially disrupt the navigational systems. Li-fi enables passengers to access high speed internet through reading and cabin lights, which enhances the safety of in-flight communication. As many as 70 commercial airlines will start using li-fi by 2025, making it faster and more cost effective for passengers.

A sample of this is below is, Underwater applications:

Most underwater vehicles that operate remotely are equipped with tethered cables for power and communication. Li-fi instead of cables allows ROVs to explore vast regions without any physical constraints. ROVs can communicate without a crew, processing the data and

transmitting it to surface operators in real time. Li-fi is an underwater powerhouse, great for military, scientific, and environmental monitoring.

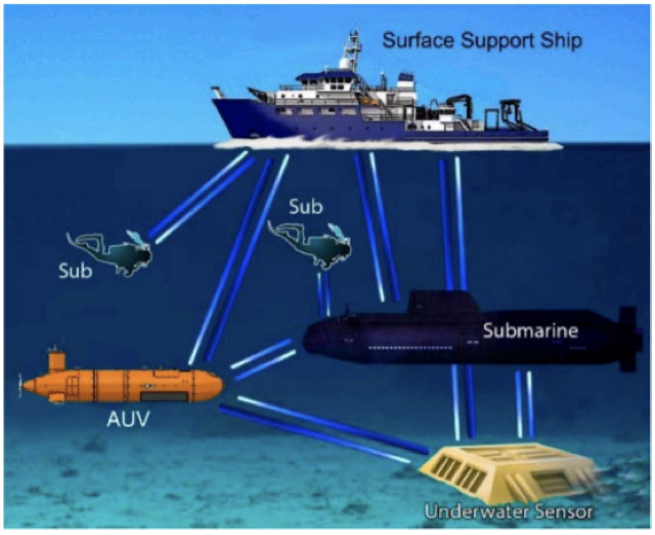

Fig. 8. UOWC

What is the purpose of the sixth, Disaster management: Li fi can be a powerful communication mechanism during natural disasters, such as earthquakes and hurricanes. Li-fi can be used to communicate with people in areas where traditional communication lines have failed, such as underground tunnels and subway systems. Bulbs can provide high speed internet access in urban areas, which increases emergency response capabilities and preparedness.

What is the purpose of the seventh, Inflammable zones: Li-fi can enable secure and rapid communication in sensitive areas, such as power plants, without the hazards of radio frequency transmission. Nuclear power plants need to be monitored regularly to ensure the grid integrity and temperature. Li fi can transmit data with minimal electromagnetic interference making it a reliable mode of communication.

What is the purpose of the eighth, Regulation of traffic: Li-fi can connect led lights to traffic signals, adding to traffic management systems. Real time traffic data can help reduceaccidents and improve traffic flow. By 2025, up to 30 smart city traffic management systems will be able to use li-fi.

Last but not the least, Defence sector: Li-fi is a huge player in the defence industry, and it has a lot of benefits.

What is the purpose of the following. Li-fi is a secure way of communication for military personnel in bases and operational environments, because there are no walls in a wall. This reduces the chances of interceptions from adversaries. What is the purpose of the second. Real time data sharing between military personnel through li-fi can enhance their situation awareness. Soldiers could get mission updates and important intelligence using li-fi without radio communications. What is the purpose of the above mentioned. Military vehicles can communicate with each other using li-fi systems based on the headlights of their vehicles. This can improve operational coordination and reduce the likelihood of friendly fire.

The purpose of the program is to provide a platform for students to showcase their skills and knowledge. Li-fi in unmanned aerial vehicles and UAVs allows high speed data transfer to command Centers. This helps to make decisions faster and more situational awareness during missions.

A sample of this is below Li-fi can be used in combat zones with radio jamming hazards, and can be used to transmit data. Troops can communicate with each other using light sources in low pressure settings.

XI. CONCLUSION

LED lighting is highly shifting into LED lighting and hence significantly reduces energy usage and service life. Wi-Fi is a well-known good wireless network and Li-Fi transmits denser wireless data in narrow spaces, and it definitely resolves the radio interference-related issues. Therefore, they are in phase.

This is one disadvantage in Li-Fi: light does not have a passage through opaque material; hence it can get very restrictive and therefore confined. Li-Fi is a great wireless communication solution but has one disadvantage.

It has high data rates and diverse applications. Research is being done to create LED bulbs that can become Wi-Fi hotspots and transmit wireless data without disruption. This breakthrough not only indicates a future with cleaner and greener air, but it also addresses the potential harmful effects of radio waves on living organisms. Li-Fi uses light as its medium for communication. It transmits data, audio, and video using LEDs with an environment-friendly approach. It has been tested in the real world and also in simulations and has been proved feasible. Li-Fi is the great advancement in wireless communication in terms of speed, security, and environmental sustainability. The new technologies, like IoT and 5G networks, can be easily combined with Li-Fi (as shown in Fig.9) in order to increase connectivity between different environments. It can be a good alternative for Wi-Fi because its limited range and line of sight make it suitable for use in high-density areas.

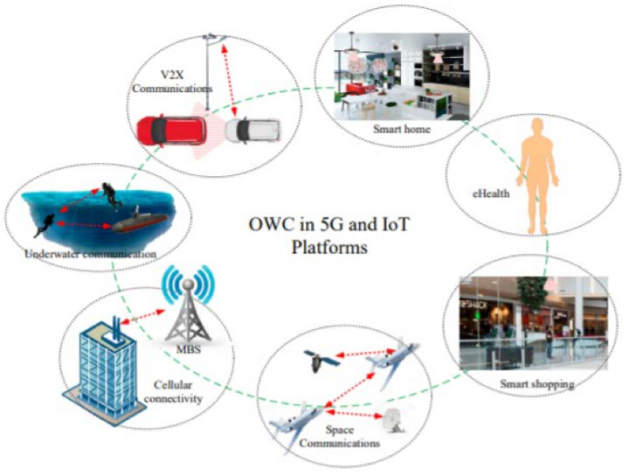

Fig. 9. OWC

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