**A Review of Free Space Optics, its Application to IoT and FSO challenges**

Gaurav Soni1,2, Manish Sharma3

1Apex Institute of Technology (CSE-AIT), Chandigarh University, Punjab, India

2Chitkara University Institute of Engineering & Technology, Chitkara University, Punjab, India

Manish Sharma3

3 Chitkara University Institute of Engineering & Technology, Chitkara University, Punjab, India

**Abstract:** Free Space Optics (FSO) is defined as an optical communication technique that sends data between two locations by using light travelling in free space. Data is conveyed via modified laser light, comparable to fibre optic communications. Instead of being contained inside a glass fibre, light pulses are transmitted through the atmosphere in a narrow beam. The three variables that influence optical transmission are absorption, scattering, and scintillation. All of this has the potential to decrease the quantity of energy received by the receiver. Carbon dioxide and water vapour in the air along the transmission route are the primary causes of absorption. Humidity and altitude have a role in their existence. This reduces the power density (attenuation) of the FSO beam, which has a direct impact on the system's availability.

**Keywords**: Free Space Optical Communication (FSO), Differential Phase Shift Keying (DPSK), VLC

**1.1 Introduction to Free Space Optics (FSO)**

With the current state of technology, there are several solutions available for data transfer. Fiber optic cable technology comes first. In the telecom sector, this is the finest option. For several applications in diverse communication connection domains, fiber is the most dependable option [1],[2],[3],[4],[5]. But fiber optic use is quite expensive. This is because to the exorbitant expenditures associated in trenching streets in order to lay fibers. Radio frequency (RF) technology is another choice. Although RF is a well-established technology, its data rate is restricted, it needs FCC authorization [6],[7],[8],[9], and it is more expensive than other forms of access. Up to 2.5 Gbps, RF technology is not scalable. There is currently a 622Mb RF bandwidth limit. For service providers wishing to expand optical networks, RF is not a cost-effective alternative to Free Space Optical. Technologies based on wire and copper constitute the third option [10]. Although copper technology is used at a larger proportion than fiber, it is unable to alleviate the bandwidth capacity constraint and connection bottleneck. The more information transmitted in copper conductors, the larger the losses; in copper cables, losses rise with frequency. Free Space Optical (FSO), the fourth and often most preferred option, is [10]. FSO offers users quicker, more bandwidth at a larger capacity. Due to the high bandwidth available (which is now up to 2.5Gbps)[12], a narrow laser beam can carry a lot of data. Additionally, FSO is affordable, easily deployable, and portable, it often costs about half as much as installing fiber optic cable [8].A promising technology for next-generation indoor and outdoor broadband wireless applications is optical wireless communication. Applications include last-mile connections that bridge the gap between end users and the current fiber optic communications backbones, short-range wireless communication links that provide portable computers network access, and even laser communications in lines that are launched into space. While outside optical wireless communication is most often referred to as free space optical (FSO) communication, indoor optical wireless communication is also known as wireless infrared communication. The terrestrial FSO systems combine some of the benefits of radio frequency equipment (wireless connectivity, quick and simple installation, and relatively low cost) with fiber optics (high data rates, no mutual interference between the FSO systems, and difficult eavesdropping on transmitted data) [10]. Broadband communication capacity utilizing unlicensed optical wavelengths is possible with FSO technology. However, differences in the refractive index occur throughout the transmission channel due to non-homogeneities in the atmosphere's temperature and pressure. Fading is caused by these changes in refractive index, which cause temporal and spatial fluctuations in the optical intensity impinge on a receiver. Such atmospheric factors may result in fading connections, which can impair FSO communication performance by increasing bit error rate (BER) and transmission delays [26]. Any network architecture may be configured for FSO, an independent protocol. Under the physical layer lies the Open System Interconnect (OSI) for FSO. The focus of this research is on the propagation of FSO in outdoor systems in relation to weather conditions, with a particular emphasis on atmospheric influence and complete attenuation. Two categories may be used to categorize the atmospheric effect: atmospheric turbulence and atmospheric attenuation [27]. Rainfall-induced scattering caused by water droplets is referred to as non-selective scattering. This scattering happens independently of wavelength. On hazy days, mee scattering predominates in total scattering coefficients. The laser wavelength and visibility both affect the amount of attenuation caused by Mie scattering. The wavelength affects the Mie scattering effect. It is crucial to examine FSO performance while taking into account a number of system characteristics. Three categories may be used to group the parameters: design, uncontrolled performance parameters, and others [8]. Design characteristics including wavelength, aperture size, beam divergence, and link range are connected to the FSO system's design. To reduce the attenuation impact on FSO, adjustments may be made to the wavelength selection, divergence angle, receiver area, transmitter area, and distance between transmitter and receiver. Weather conditions are connected to uncontrollable characteristics. Rainfall rate and raindrop radius are two uncontrollable factors in rainy circumstances. Visibility is correlated with the uncontrolled characteristics of hazy circumstances. The scattering coefficient impact, atmospheric attenuation, and total attenuation may be used to assess the performance of rain and haze situations. Rain, haze, and fog are examples of unfavorable weather conditions that might affect FSO systems[6]. These factors all work to weaken light and may obstruct the atmosphere's light path. As a consequence, there may be disruptions and interruptions in the communication process. Thorough weather conditions research must be done prior to the FSO installation procedure on tall structures. This is to guarantee that, even in inclement weather, FSO will continue to function with enough transmission power and low losses.

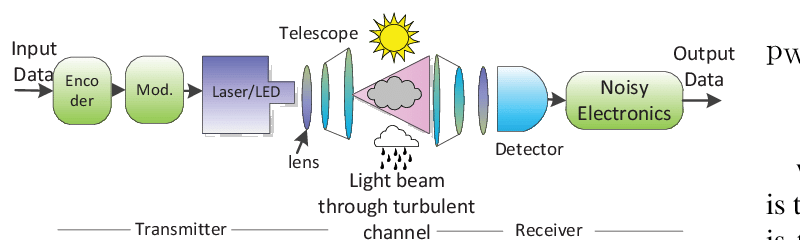


Fig. 1.1: Free Space Optics- Block Diagram [10].

Free Space Optics is an optical technique that provides dependable high-bandwidth connections faster and more affordably than standard physical fiber systems by using invisible light beams over the air (instead of fiber optic cable). A single light source communicates to a single receiver in conventional FSO technology. A throughput of 1 Gb/s [1] or more is usual for these systems. The transmission range is quite constrained, ranging from 200 to 1000 meters (standard systems function up to 500 meters). These devices have a 99.9 percent reliability rate in clear situations, with significant variations based on weather and distance.

FSO refers to wireless point-to-point connections when there is an unobstructed line of sight between the points. Currently, full duplex optical communications at gigabit per second rates across metropolitan distances of a few city blocks to a few kilometers are made possible by this line-of-sight technology. This provides connection without requiring the installation of fiber-optic cable or the acquisition of spectrum licenses, and it is more than sufficient to handle data, phone, and video traffic. The optical transceivers are usually installed in big windows or positioned on building roofs. A representative FSO system transceiver is seen in figure 1.[3]. To achieve complete duplex functionality, the optical transceiver is made comprised of a laser transmitter and a detector. FSO uses a wavelength that is somewhat smaller than visible light to function in the infrared portion of the electromagnetic spectrum[32]. Since this huge frequency or tiny wavelength is in the global unlicensed spectrum (more than 300 GHz), no spectrum license is needed. The 850nm and 1550nm wavelength standards have been accepted by the laser industry, and FSO has followed suit. Although the two wavelengths' differences may not seem like much, they are really highly important in the business sector. The cost of manufacturing the lower wavelength (850 nm) is a tenth of that of the bigger wavelength (1550 nm) [3]. So why not just use the 850 nm wavelength for operations? This is so that considerably more power can go further at a faster data rate thanks to the longer wavelength. Both standards have potential for success in the market and both wavelengths have applications. While certain infrastructures or places demand more bandwidth across longer distances or higher power options, such as in areas known to have fog, many organizations today may just need the smaller, less expensive bandwidth.

**1.2 FSO Benefits**

A network of linked free-space optical communication lines is the foundation of wireless optical networking, a carrier-grade last-mile technology. The network offers many paths to every building, fault tolerance for network outages, and access to other communication networks. Like the ones on the market now, FSO systems have the following advantages: no FCC license is needed; high capacity; quick deployment; easy integration; resistance to jamming; and, because of the narrow laser beam, superior signal security than conventional wireless options. Furthermore, the lasers used in FSO systems are secure. The beams are undetectable to the human eye because of the relatively poor sensitivity of the 850 and 1550 nm wavelengths. When standing immediately in front of a node and looking straight down the line-of-sight, you will see a little red dot from the transmit optics that is barely visible inside a cone that is around 0.1 degrees in diameter. Two crossing beams do not interact with one another in the air. The link is momentarily lost if a bird fully clogs the tiny transmit or receive aperture, which has a diameter of two inches. Upon the bird's passage through the beam, the optical connection becomes active again automatically.

**1.3 FSO Limitations**

However, there are a few issues with FSO functioning in this spectral range, including as beam wander, scintillation, scattering, and beam spread[7]. The definition of scintillation is the fluctuations in light intensity that occur over time or space due to air turbulence, such as wind or temperature gradients. There are patches of light and dark in the lighted region at the receiver due to scintillation. Scintillation is not a major problem in any FSO system at the short link ranges considered. The reduction of beam power brought on by precipitation or fog is known as scattering. The beam widening due to distance is known as beam spread. Beam wander is the minor displacement of the laser beam due to external factors like building sway. Generally, 99.999% availability is the goal of design for free space optical networks.

**1.4 Characteristics of Free-Space Optical Transmission**

The technique known as Free Space Optical Communication (FSO) has several important benefits:

* Data Transfer Rates: FSO systems are well-suited for applications that need rapid and extensive data transmission due to their ability to provide high data transfer rates.
* The transmitter and receiver must have an unobstructed line of sight in order for FSO communication to take place. This function guarantees safe, one-on-one communication.
* Because it is difficult to intercept optical signals, FSO provides fundamentally secure communication and improves data privacy.
* Reliability in High-RF-Noise Environments: FSO is unaffected by radio frequency congestion and electromagnetic interference, allowing it to function reliably in such settings.
* Financial trading and real-time video streaming are two applications that benefit from FSO systems' reduced latency.
* Regulatory burdens are reduced since FSO does not need licensing for certain frequency bands.
* Small Range: FSO is best used for applications that do not need long-distance communication because to its relatively small range as compared to other wireless technologies.
* Susceptibility to Weather: Unfavorable weather conditions, such rain, fog, or atmospheric disturbances, may affect the performance and dependability of FSOs.
* To overcome weather-related obstacles, FSO systems often include optical connections, photodetectors in receivers, and lasers or LEDs in transmitters. Adaptive optics and beam-steering devices are also common components.

**1.5 FSO Link Budget Analysis**

This section cover’s the FSO power link budget Analysis, the link availability of the connection, and the mathematical handling of the attenuation due to scattering.

Fig. 1.2 displays an example of the power level diagram of an FSO deployed at a distance of about 1 kilometer. A laser diode at one side of the FSO and a photodiode at the other are visible attenuations caused by different portions of the FSO, which are represented by the intervals between the two adjacent points on the horizontal axis.

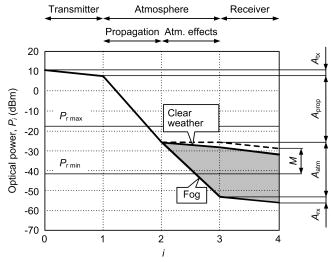


Fig. 1.2: FSO power level diagram

It is obvious that the received optical power at the receiver can be written in the form [40],

 [dBm] (1.1)

where P0 is the average optical power of a light source (laser or LED), Atx is the attenuation loss in the lens and the coupling loss between the laser and the transmitter lens, Aprop is the attenuation of the beam as a result of propagation loss, Aatm is the random losses resulting from atmospheric phenomena (turbulence and scattering), and Arx is the attenuation and reflection at the lens as well as the coupling loss between the receiver lens and photodiode.

In order to achieve a successful detection, the power on the photodiode PRX's active area must fall between the lowest and maximum received optical power for the specified BER, or the receiver sensitivity Prmin and receiver saturation Prmax. It is clear that this criterion is not met for fog in the case provided.

**1.6 WAVELENGTH ANALYSIS**

For FSO systems, the "optical transmission windows," eye safety concerns, and costs are the main factors in choosing the optical wavelengths. The choice of wavelength is influenced by meteorological factors as well as the accessibility of transmitter and receiver parts. Cost considerations are important, and meeting space requirements influences design as well. Longer wavelengths (beyond the "dangerous" wavelengths for eye safety) are the recommended choice based on air circumstances and laser safety rules. The wavelength that is employed is an important parameter in the field of FSO (wavelength is chosen over frequency in optics).



Fig. 1.3: Wavelength attenuation in dependence of visibility

Three primary bands for optical radiation are suggested by the International Commission on Illumination: IR-A (700 nm – 1,400 nm), IR-B (1,400 nm – 3,000 nm), and IR-C (3,000 nm – 1 mm). For the time being, a popular sub-division plan is shown.   
NEAR-INFRARED (NIR): mostly employed in fiber-optics (minimal attenuation losses),this-wavelength-from-750nm-to-1.4μm.   
SHORT-WAVELENGTH INFRARED (SWIR): the predominant spectral band for long-distance communications is between 1,530 and 1,560 nm, with wavelengths ranging-from-1.4μm-to-3μm.   
Long-wavelength infrared (LWIR): wavelengths from 8 μm – 15 μm; "thermal imaging" zone; utilized in military applications for missile guidance. Mid-wavelength infrared (MWIR): wavelengths from 3 μm – 8 μm. Only thermal emissions from an item may be used by sensors to create images of it; additional light is not needed.   
The range of FAR-INFRARED WAVELENGTH (FIR) is between 15 μm and 1 mm. When discussing laser communications, it is essential to take into account this crucial point: restrictions on security, especially in relation to concerns about eye safety. Standards for the transmission of optical power that is safe for the eyes were created by the International Electrotechnical Commission and other organizations. Various degrees of classification are applied to all laser items based on the potential for maximum harm. There are four different laser classes: "Class 1" (not harmful) to "Class 4" (extremely hazardous, emitting power more than 0.5 Watt). The outer layer of the eye, called the cornea, functions as a band-pass filter, allowing only wavelengths between 400 and 1,400 nm to get through. This indicates that light energy released outside of this area is absorbed rather than reaching the retina. Stated differently, the use of laser communications at wavelengths less than 400 nm and longer than 1,400 nm offers the potential benefit of increased energy densities inside the laser beam. The visible light spectrum extends from 380 nm to 780 nm. The eye may detect laser sources operating in this area and respond accordingly by closing its eyes, but only within certain parameters such as exposure duration and output power. That being said, the fact that the laser light is still focused straight on the retina at 1,064 nm yet cannot be detected makes other technologies such as this one very dangerous. There is no guarantee that someone exposed to that level of radiation won't have negative consequences. It is known as the Maximum Possible Exposure (MPE) characteristic quantity. It describes an upper limit to which an individual may be exposed without risk or long-term consequences, such as biological alterations in the skin or eyes. It is contingent upon the laser's wavelength, power output, and exposure time. When it comes to choosing workable wavelengths for fiber-switching connections, the older systems (around 850 μm) are essentially riskier than the more recent ones (1,550 nm or even 10 μm). In the latter scenario, this wavelength and the hazardous region are separated by orders of magnitude. In comparison to NIR, LWIR and 1.55 μm systems have a much higher MPE level. A 1,550 nm FSO system may transmit more than 10 times the power of a system operating at 780 nm, provided that both systems have the same safety class. Additionally, LWIR systems have even greater transmission power than 1,550 nm systems. Since the initial "optical window" for optical fibers occurs at 850 nm (NIR, IR-A), the most affordable and well-researched components need to be accessible. Aluminum-gallium (AlGa) is the material used in semiconductor lasers operating at this wavelength. Diode lasers may achieve high efficiency of up to 50%. The second "optical window" is located at around 1,300 nm and has lower costs than the third "optical window," which is located at 1,550 nm. Because laser and eye safety regulations are crucial in FSO, 1,5xx nm is the ideal wavelength. Furthermore, 1,300 nm technology is just incidental to FSO. Several recent investigations and efforts have failed in the instance of 1,064 nm. The most common kind of laser at 1,064 nm wavelength is the neodymium yttrium aluminum garnet, or Nd:YAG, laser. Massive power transmission is possible with these lasers, which are used in coherent systems with very stable Nd:YAG oscillators. The laser source has excellent coherence, making it a strong choice for homodyne systems. These characteristics allow homodyne binary phase-shift keying (BPSK) modulation to be implemented. These systems' high sensitivity allows for tiny aperture widths for the optical receivers, which is advantageous. Another experiment with a carrier wavelength of 1,064 nm has been conducted in space with success. The wavelengths of around 1,550 nm in conjunction with OOK and direct detection are often used in fiber optical transmission systems. The wavelengths are part of the optical C-Band and may also be used as a good space connection option. Although quick wave-front correction systems (adaptive optics) may reduce air index of refraction turbulence and enable coupling of the received signal into a mono-mode fiber at the receiver, current methods are not as sensitive as coherent systems. At room temperature, LWIR emitters with wavelengths between 8 and 10 μm are capable of functioning. Solid state thermoelectric coolers may be used to create the cooler device. It contributes to consistent heat dissipation. Direct modulation of QCLs takes place. Using QCLs eliminates some issues such as restricted bandwidth and extinction ratio. Physical propagation benefits such as decreased light scattering are the primary driving force for the shift to MWIR or LWIR systems, as previously mentioned. Longer wavelengths may be able to improve throughput and connection availability in decreasing situations such as fog or clouds. The beam traveling through the water particles is absorbed and scattered, resulting in attenuation caused by fog. Numerous physical characteristics, including the distribution of particle sizes, the amount of liquid water in the fog, its temperature, and its humidity, define fog. Mie scattering creates attenuation because the size of fog particles is similar to the wavelength at which optical and near-infrared signals transmit.

The safety of the laser and eyes is a crucial factor. Compared to longer wavelengths, the shorter wavelengths have higher laser power restrictions. Additionally, attenuations resulting from scattering are less significant at longer wavelengths. The wavelengths of the lasers employed in the FSO systems make them safe for human eyes. These wavelengths do not, however, have the same safety standards. Without endangering human vision, technology using a wavelength of 1550 nm may securely transfer 100 times more optical power than 750 nm and 50 times more optical power than 850 nm.

**1.7 IoT Practical Applications**

In recent years, IoT's flexibility has gained a lot of attention. Having an IoT-based gadget has many benefits[10].

1) Personal Home Automation System: The most well-known example in this category is the Home Automation System.

Wemo Switch Smart Plug: It is one of the most helpful gadgets in the Switch, a smart plug that connects home devices. It connects into a standard socket, takes any device's power connection, and can be turned on and off by pressing a button on your smartphone[1].

2) Enterprise: There are many uses in the enterprise sector. For example, an environmental monitoring system, a smart environment, and so on.

The Nest Smart Thermostat is an internet-connected thermostat, A smartphone app is now available, which enables users to change the temperature and schedules[9].

3) Utilities: The most beneficial applications in the different utility areas include smart metering, smart grid, and water monitoring systems.

4) Energy Management: The most prominent example in this category is Advanced Metering Infrastructure.

5) Medical and Health Care: Examples of IOT in the medical sector include remote health monitoring and emergency alerting systems.

Health patch Health Tracker: It may be utilized for patients who are unable to see physicians, allowing them to get remote ECG, respiration rate, heart rate body posture, fall detection, skin temperature.

**1.8 Use and Importance of Optical based Technology in the IoT**

Photonic and Light technologies have played a major part in the development of the Internet of Things and its use in smart infrastructures, and will continue to do so in the future. Fig. 1.4 depicts an example of optical technology placement inside a tiered IoT architecture[1].

Transport and mobility settings need a high degree of reliance on optical communications. Beyond optical fibre and LED/laser sources, photonics is influencing automotive IoT applications via the networking of light detection and ranging (lidar), time-of-flight and visual instrumentation for both ADAS and autonomous cars[6].

"An emergent area, the 'Internet of Vehicles or IoV,' is starting to take form around V2X [Vehicle-to-Everything] ubiquitous communications," taking use of VANET [Vehicular Ad-Hoc Networks] expertise and the new technologies of the Internet of Things. “Passive or active photonic sensing technologies—mainly cameras and lidar—enable object/obstacle detection, collision avoidance, identification/classification and tracking, blind spot detection, lane maintaining, adaptive cruise control, parking assistance, and eventually, complete autonomy. Mobility apps that rely on wireless connections would not exist without photonics[1].

Many industries are embracing photonic technology. There is a wide range of applications for photonic devices, from sophisticated research to everyday living. Laser printing, fibre optics, and high-power lasers are all examples of photonic devices in action. Photonic devices have a wide range of uses, from chemical synthesis to data transmission, laser defense, fusion energy, and medical diagnostics, to name just few.

There are lots of instances of photonic devices and systems being used in smart infrastructures to detect different physical and chemical characteristics like as, strain, temperature, stress, ,tilt, acceleration, rotation, mechanical vibration, speed, fluorescent, refractive index, absorbance.

Semiconductors and photonics will be crucial to the success of AI and IoT technologies. Light theory has already been developed, and it is projected that photonics will become a big investment.



Fig. 1.4: Internet of Thing Layering Concept-Architecture [8].

**1.9 Role of VLC in IoT**

Visible light communication (VLC) has recently developed as an alternative to radio frequency (RF) technology . Wi-Fi and other existing communication bands, such as those used in industry, science, and medicine, often lack open channels. It's possible to communicate using photodiodes and photodetectors in the visible light spectrum, with free space serving as the channel of transmission and photodiodes/photodetectors as the receivers, using VLC (visual light communication). Short-range and maybe even long-range communication may be possible using VLC in the future, according to the available data. The use of appliances to communicate between cars, infrastructure, or simply as an alternative to traditional local area networks may be possible in the future [2].

Ensuring a permanent position for optics in practically every communications-intensive IoT application and changing our definition of connection. Optical fibres and highly efficient laser diode sources are the foundation of high-bandwidth optical communications networks. However, light-emitting diodes are crucial to many IoT applications because they allow smaller, more private networks. Originally designed to replace incandescent and halogen bulbs, LEDs offer ultralow energy consumption, long life, and a compact design that promises more than simple illumination, if LEDs continue their tremendous rise in terms of energy performance, the next step is of course connectivity via a system called LiFi or Li-Fi (Light Fidelity), or luminaries that communicate with other equipment[1]. Fig. 1.5 shows the LED lighting fixture integrated with LiFi technology [1].

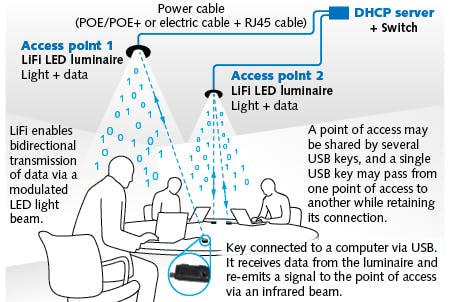


Fig. 1.5: LED lighting fixture integrated with LiFi technology [1].

The modulation of light from LEDs is used to transmit signals in LiFi. At the Fraunhofer Henrich Hertz Institute (HHI) in Germany, researchers have shown the ability to transport data at a rate of 3 Gbit/s using regular LED light bulbs. The same technology was able to provide 500 Mbit/s in a real-world scenario (such as a trade show). It is suitable for places where radio frequencies are restricted due to interference with delicate devices, such airports and hospitals, where every light bulb may be turned into a network link through LiFi communications. For many IoT applications, the fifth generation of wireless communications technology, 5G, will be critical.

**WoC and 5G**

With tree topologies and split ratios of 1:256, passive optical networks are commonly used. In support of future 5G network development, the IEEE and ITU-T standards NG-EPON (IEEE) and G.hsp.x (ITU-T) are expected[1].

Wireless Optical Communication (WoC) is defined as an optical communication technique that sends data between two locations by using light travelling in free space[1]. The performance of the WoC System is also affected by the beam divergence angle. When it comes to connecting radio cellular base stations to the core network, the traditional techniques include using microwave connections, time-division multiplexed leased lines, digital subscriber lines, and asynchronous transfer mode (ATM), for example (E1/T1). Future 5G networks demand high data rates in the tens of Gbit/s range, and traditional fronthaul and backhaul deployment technologies are unlikely to meet these requirements. For those who want a faster and more long-distance connection, optical access networks are an option. Energy-efficient as well. In order for optical fiber-based transmission to work, existing fibre must be available and cost-effective to build. [6] In order to establish a high-capacity wireless backhaul network, optical access technologies paired with moderate and high-speed radio connections such as microwave and E-band are a suitable solution[7].

Baseband units (BBUs) and remote radio heads (R-Hs) have been separated in recent improvements toward a cloud-based radio access network (C-RAN) (RRH). In a 5G scenario with a channel bandwidth of 100 MHz and 32 antennas, the needed common public radio interface (CPRI) bandwidth is 157 Gbit/s [8].

At the absolute least, the roundtrip delay must be at least 250 seconds [9]. In 4G networks, this isn't a problem since RRH and BBU are so near together. The BBU pool may be placed on a cloud-based server rather than a local server, making it impossible to meet the strict low-latency criteria.

They're all different kinds of equipment for transmitting and processing data (NGC). Predicted fronthaul connection capacities vary from 4 Gbit/s/3 Gbit/s, depending on the split selection. In addition to access, local area, and personal area networks, optical wireless communication systems may also be employed in proximity communication[5].

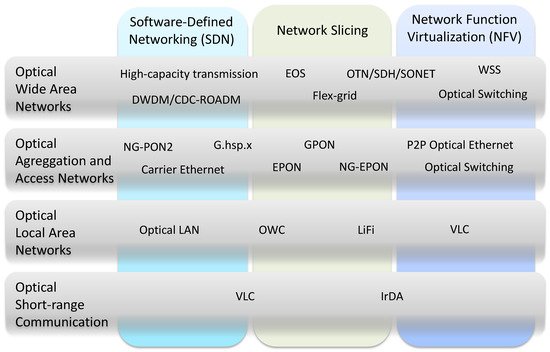


Fig. 1.6 : Optical communication technologies [2]

Optical wireless systems using the infrared and visible portions of the optical spectrum, as well as radio frequency (RF) technologies, have lately been the subject of a great deal of study. [3] IEEE 802.15.7's VLC and LiFi standards, which are referred to as visible light communication and light fidelity, may benefit a wide range of smart systems and smart infrastructure applications. Intelligent buildings, factories, warehouses, transit systems, and hospitals all have communication and location applications[2].Fig.1.6 shows an overview of several advanced networking technologies and techniques.

#### **1.10** **Energy Consumption**

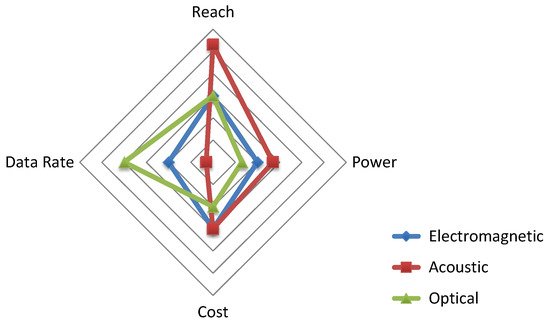


Fig.1.7: Underwater wireless sensor networks based on electromagnetic, acoustic, and optical waves- comparison model [1].

Sonic waves have a far greater range when used underwater, but optical beams have a much shorter range. The adoption of an acoustic-optical hybrid approach might, for example, circumvent this constraint. The absence of a battery or power source in the field may be a substantial benefit for certain applications that use fibre infrastructure. Big data centres' internal networks might benefit from similar energy-saving and scalability-enhancing technologies and ideas.

For Internet of Things (IoT) applications, sensors and communication systems must be developed and deployed with low power consumption in mind. Sensor nodes in the field, on the other hand, that aren't connected to the energy grid will have to deal with a limited battery capacity for many years. There is a direct correlation between the amount of energy used by wired and wireless networks, data storage and processing systems, and the amount of environmental damage they do. When evaluating an IoT implementation's energy use, it is critical to include the energy used by all components, including sensor and actuator nodes, data transmission and networking devices in access and core regions, and data storage/processing devices like network and application servers. Sensor nodes use a wide range of power, depending on the application and design. The application's parameters for selecting the suitable sensing unit and associated components and circuits have a significant impact on data processing, power supply management, and data transfer (i.e., transceivers). Changing the sensor node's design may improve its battery life by reducing its energy usage. A wide range of sensing ideas necessitates different levels of signal processing complexity. If performance, accuracy, and energy consumption requirements are fulfilled, optical sensors may be a good fit for a particular application.. There are advantages and disadvantages to utilising optical sensors to provide more accurate and quicker measurements, but this comes at the expense of increased energy consumption and more complicated design, for example, in systems based on optical spectroscopy for detecting gas characteristics [2].The advantages of optical technology over acoustic or electromagnetic waves in applications like underwater wireless sensor networks shown in Fig. 1.5 are high data rates, cheap costs, and low power consumption. On the other hand, underwater acoustic waves have a far faster reaction time. An acoustic-optical hybrid may be able to address this issue. Some applications may need a system without an external power source, such as a battery or electricity, in order to operate. The energy efficiency of optical communication technology has already been extensively examined. Data sent over optical fibre is more energy-efficient than data sent by wired radio, according to a new study. It is more than six orders of magnitude more efficient to use optical underwater communication technologies than earlier wireless and coax cable methods. It is possible to considerably increase the efficiency of the network infrastructure by using cutting-edge ideas and energy management solutions for both submarine transmission systems as well as access, aggregation, and core network regions.

**Summary**

With tree topologies and split ratios of 1:256, passive optical networks are commonly used. In support of future 5G network development, the IEEE and ITU-T standards NG-EPON (IEEE) and G.hsp.x (ITU-T) are expected. Wireless Optical Communication (WoC) is defined as an optical communication technique that sends data between two locations by using light travelling in free space. The performance of the WoC System is also affected by the beam divergence angle. When it comes to connecting radio cellular base stations to the core network, the traditional techniques include using microwave connections, time-division multiplexed leased lines, digital subscriber lines, and asynchronous transfer mode (ATM), for example (E1/T1). Future 5G networks demand high data rates in the tens of Gbit/s range, and traditional fronthaul and backhaul deployment technologies are unlikely to meet these requirements.

**REFERENCES**

[1] Gerd Keiser “Optical Fiber Communications,” McGraw-Hill, 1991.

[2] A. Ahmed, Farid, Steve Hranilovic, “Outage Capacity Optimization for Free-Space Optical Links With Pointing Errors,” Journal of LightWave Technology, IEEE, Vol. 25, No. 7, July 2007, pp.1702–1710.

[3] Zabidi, Islam, Al-Khateeb & Naji, “Analysis of Rain Effects on Terrestrial Free Space Optics based on Data Measured in Tropical Climate,” IIUM Engineering Journal,Vol. 12(5), 2012 pp.12–17.

[4] M. Tatarko, Ovseník and J. Turan, “Availability and Reliability of FSO Links Estimated from Visibility,” Carpathian Journal of Electronic and Computer Engineering, Vol. 5, 2012, pp. 121-126.

[5] Nazmi Mohammed, Amr S. El-Wakeel and Mostafa H. Aly, “Pointing Error in FSO Link under Different Weather Conditions,” International Journal of Video & Image Processing and Network Security, IJVIPNS-IJENS, February 2012, Vol. 12 No: 01, pp.6-9.

[6] Ali Mazin, “Atmospheric Turbulence Effect on Free Space Optical Communications,” International Journal of Emerging Technologies in Computational and Applied Sciences (IJETCAS), 2013, pp.345-351.

[7] Sanamdeep Singh and Gaurav Soni, “Pointing error evaluation in Free Space optical link,” IET, 2013, pp.365-370.

[8]G. Ruffato, M. Massari and F. Romanato, "Diffractive optics for OAM-mode division multiplexing of optical vortices Design, fabrication and optical characterization," 2016 IEEE 7th International Conference on Advanced Optoelectronics and Lasers (CAOL), Odessa, Ukraine, 2016, pp.148-150.

[9] Y. Kaymak, Fathi-Kazerooni, Rojas-Cessa, Feng, Ansari, N. Zhou, “Beam with adaptive divergence angle in free-space optical communications for high-speed trains,” 2018, arXiv preprint arXiv:1812.11233, pp.1702–1712.

[10] S.Aleksic, “Survey on Optical Technologies for IoT, Smart Industry, and Smart Infrastructures,” Journal of Sensor and Actuator Networks. 2019, Vol. 8(3),pp. 47-51.