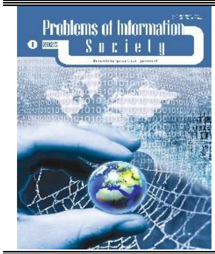

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Wireless optical communication technologies in 5G and 6G network infrastructure: problems and solutions

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ABSTRACT

The article broadly examines the importance of choosing a wireless data transmission technology in 5G and 6G networks with speeds exceeding 1 Gbit/s, the methods and advantages of technological solutions applied in this area, and also conducts a comparative analysis of various approaches in order to increase efficiency in accordance with the increasing data transmission requirements of the modern era. Scientific research conducted in this area reveals serious problems related to the existing technological shortcomings of the data transmission method using radio waves, in particular, the limited ability to meet the requirements for high-volume data transmission, as well as the impossibility of effective use of radio communication channels in 5G and 6G networks due to technological and physical limitations. These problems are mainly related to the lack of sufficient spectrum resources, increased electromagnetic interference, and signal attenuation over space and time. Consequently, the continuous development of communication technologies and the search for alternative methods remain a priority for solving urgent problems in this field. In this regard, the article describes the features, main characteristics and requirements of new generation mobile networks (5G/6G). The classification of wireless optical communication technologies, their physical characteristics, working principle and comparative analysis with other wireless technologies are reviewed. The issues raised in this work are explored and summarized. According to the results of the study, the successful installation of optical communication 5G/6G networks can be used as an effective solution.

1. Introduction

Recently, the rapid increase in the data volume has created a number of problems in the process of their sharing (transmission and reception), as well as in the field of their storage and processing. This, in turn, leads to the improvement of currently available network technologies or the creation of new communication tools.

Mobile communication is a type of radio communication in which users communicate with each other using a network of base stations. Base stations are designed to receive and retransmit signals from user devices (receivers and transmitters). Radio communication is a method of transmitting information over a distance using radio waves.

Currently, radio communication, created on the basis of radio frequencies, is widely used for various wireless connections. However, this type of communication often faces the following limitations (Candice, 2014):

- coverage limitation;
- dependence on weather conditions;
- effect of various obstacles;
- complexity of frequency regulation rules.

In modern times, third (3G) and fourth (4G) generation mobile radio communication technologies are widely used. The characteristics of the technologies referring to these generations are determined by the properties of the data transmission channel used for them. However, wireless technologies based on radio frequencies are unable to meet the requirements of the currently implemented 5G and 6G networks, which are planned for implementation in 2030. Consequently, researchers are trying to identify a new type of communication to meet the exponentially increasing requirements in communication networks (Zaman et al,, 2019).

Wireless communication based on the optical spectrum is considered the most qualitatively active type of communication for future communication systems, including fifth (5G) and sixth (6G) generation networks.

2. Related works

Wireless optical communication (WOC) is a modern communication technology that uses different ranges of the electromagnetic spectrum for the transmission of information signals, based on the use of visible, ultraviolet and infrared light rays. This technology works on the principle of transmitting an optical signal through air or space and is superior to traditional wired communication systems, especially in terms of high data transfer speed and security. Accordingly, networks based on 5G/6G technologies, together with the development of modern information and communication technologies, provide very high data transfer speeds, are distinguished by lower latency and wider coverage. Network systems built on this technology will provide a wide range of applications for both individual users and large enterprises, accelerating further digital transformation. Wireless optical communication can provide low latency, longer distance communication and security, as well as solve the problems of data transfer speed that existed in previous generations. (Ghassemlooy et al., 2017)

WOCs have attracted wide research interest due to their characteristics.

5G and 6G communication networks, artificial intelligence, Internet of Things (IoT) should form the basis of the modern digital economy.

Internet of Things (IoT) is a concept of a data transmission network between physical objects. These objects are equipped with technical tools and technologies to interact with each other or with the external environment.

The IoT network allows for real-time communication between various systems in a number of social, industrial and commercial applications. The number of end-user devices connected to the IoT network is constantly increasing, and as a result, a large amount of data is continuously generated in the IoT network. WOC technology should play an important role in the exploration, monitoring and joint use of resources in such networks consisting of massively connected devices. The low power consumption and high security requirements necessary for IoT networks established with optical communication are considered to be the main advantages of WOC (Al-Fuqaha et al., 2015).

Specific features and requirements for the 5G communication system have already been formulated, the technology has been developed and fully deployed in some countries since 2020. 5G mobile communications offers new services of very high quality. These services cover two of the most important network characteristics: performance and reliability. 5G is characterized by the following communication services (Agiwal et al., 2016):

- ultra-high system efficiency;
- ultra-low latency;
- ultra-high security;
- collective connection of devices;
- ultra-low power consumption.

The 6G communication system is expected to be launched between 2027 and 2030. The 6G specification has not yet been fully defined, but a list of research questions has already been formulated. The main provisions are:

- increasing the transmission speed (traffic);
- increasing the number of connections;
- reducing delays;
- increasing security;
- increasing energy efficiency;
- improving the user QoS level;
- increasing reliability.

It should be noted that the main fields of development and improvement of communication systems are similar. However, conducted studies show that the 6G communication system will become a global communication environment and the level of service will be several times better than that of 5G (Jiang et al., 2023).

The main objective of this study is to analyze in detail the role of wireless optical technologies in the development and increase of efficiency of 5G and 6G networks, in providing high-speed data transmission capabilities, in optimizing energy efficiency and in increasing the stability of the overall network infrastructure, as well as to assess the application prospects of these technologies in the modern telecommunications field.

Furthermore, the potential contribution of wireless optical technologies in increasing spectral efficiency in 5G/6G networks, improving connection quality and reducing network delays are evaluated within the framework of the study, and the advantages and limitations of these technologies compared to traditional wireless communication systems are determined. At the same time, possible technical and economic difficulties of this approach are examined and recommendations on future development directions are presented.

The main purpose of the presented article is to comprehensively analyze the key role played by wireless optical communication technologies in the successful implementation of 5G and 6G networks, which are of great importance in the technological development of modern and future communication systems, and the advantages provided by these technologies, such as high transmission speed, broadband data sharing, energy efficiency and spectral efficiency.

Problem statement. The problem statement regarding the technological characteristics required to ensure the functionality of 5G and 6G networks involves a comprehensive and detailed determination of the criteria to provide high transmission speed, low latency, broadband communication capabilities and the effective connection of multiple devices simultaneously. In this context, the main attention should be paid to the specifications of the technologies required for the development of modern communication networks, their performance indicators and the solutions proposed to increase operational efficiency. Moreover, to optimize these criteria, a comprehensive analysis of innovative approaches, including the application possibilities of wireless optical technologies and the effectiveness of their integration with traditional systems, are required. The requirements of these networks, such as high speed, reliability and wide coverage, are taken into account.

This article analyzes the characteristics, capabilities of various WOC technologies, examines the application areas and advantages of each technology separately. It focuses on the physical capabilities of WOC and technical factors affecting its application. It discusses how these technologies can be used in 5G/6G, IoT networks. It evaluates how the potential of WOC can contribute to network performance. At the same time, existing practical examples and WOC-based systems are presented. WOC is recommended to be a more effective and practical solution for 5G/6G and IoT networks.

3. Materials and methods

3.1. WOC technologies

The wider range of the optical spectrum compared to radio frequencies is recognized as a promising solution for the development of 5G, 6G and IoT networks.

Advantages of WOC technology compared to radio communication may include (Muhizi et al., 2017):

- wide range;
- high data transfer rate;
- low latency;
- high security;
- low costs;
- low energy consumption.

The distance between the objects to be communicated can vary from a few nanometers to several thousand kilometers. In this case, effective inter-object communication can be achieved by deploying various WOC systems.

Key technologies for WOC systems may include (Arnon et al., 2012):

- visible light communication;
- Light Fidelity, or Li-Fi;
- optical camera communication;
- open space (atmospheric or free space optics) optical communication.

The technologies listed above have many differences and similarities. In particular, they use different types of beams and receiver/transmitter devices. Therefore, each of these technologies has its own advantages, disadvantages and limitations for application.

Thus, WOC technologies can play an important role in the development and implementation of 5G, 6G and IoT networks due to their current capabilities. By applying WOC technologies, 5G, 6G and IoT networks planned to be installed in the future should be improved accordingly both technologically and in terms of applications. The requirements for 5G, 6G and IoT networks are given below:

5G networks. The fifth generation of mobile communications provides improvements in a number of network characteristics compared to previous ones. This is necessary to effectively support modern heterogeneous multimedia applications.

The main requirements for 5G networks can be summarized as follows (Yu et al., 2017):

- Large-scale traffic. The amount of data per unit area should be hundreds of times greater than that of 4G networks;
- Large-scale mass connectivity. The number of devices connected to a 5G network can be 10 times greater than that of 4G networks;
- High user data transfer rate. The data transfer rate reaches 10 Gbit/s, which is 10-100 times higher than that of 4G;
- Low power consumption. 5G systems should consume 90% less power than 4G systems;
- Extremely low latency. Latency in a 5G network should be less than a millisecond (sub-millisecond).

Key concepts and features of 5G networks may include (Agiwal et al., 2016; Buzzi et al., 2016):

- Dense network. To ensure high quality of service (QoS), maximum data transfer rate (bandwidth, traffic), and mass connections, the deployment of 5G networks will be denser than that of 4G networks;
- Small mobile networks. This is a mobile communication radio block consisting of inexpensive, portable antenna systems with minimal power consumption and deployed close to each other (several tens or hundreds of meters). Such densely placed mobile devices allow for high-quality communication in any area of the city, as well as in indoor spaces. 5G communication systems use the concept of small mobile networks;
- High spectral efficiency. 5G systems will guarantee efficient use of the frequency spectrum by using multi-channel input/output and sophisticated coding schemes. In this regard, spectral efficiency in 5G networks should be at least three times higher than that of 4G;
- Cost-effectiveness. Lower network equipment, installation costs and lower energy consumption of network, as well as user equipment.
- Redistribution of traffic to small mobile networks. Reduction of the load of macro-mobile networks and distribution of data volumes to local small mobile networks.

6G networks. Requirements for 6G networks have not yet been standardized. Given the current development trends of communication networks, it can be assumed that the data transmission rate to the device from tens of Qbit/s to several Tbit/s will be one of the main requirements for sixth-generation networks.

The 6G networks are projected:

- to be characterized by a data transfer rate 1000 times higher than that of 5G;
- to provide longer-range communication with ultra-low energy consumption and latency of less than 1 ms;
- to use spatial multiplexing (MIMO), high spectral efficiency (100 bit/s/Ghs);
- to provide ultra-high security, reliability and low energy consumption compared to available mobile generations (Banafaa et al., 2023).

3.2. IoT networks

The main requirements for IoT systems are as follows (Akpakwu et al., 2017):

- low cost of equipment;
- easy and low-cost installation;
- high energy efficiency;
- high security and privacy;
- support for a large number of devices.

Existing radio communication devices cannot fully meet the requirements for the above networks.

3.3. Problem solution

The development of wireless optical communication technologies in 5G and 6G networks attracts attention as one of the main technological solutions that meet the requirements for high data transfer rates and low latency. However, certain problems arise during the application of these technologies, including the effect of atmospheric conditions on optical signals, limited line-of-sight distance, high energy consumption, and complexity of equipment. Solution of these problems may include the use of adaptive optical systems, the application of advanced optical lenses for amplifying and directing light beams, the creation of hybrid wireless network structures, as well as approaches such as optimizing data transmission using artificial intelligence and machine learning methods. Thus, research in this field may create conditions for the creation of more effective and sustainable wireless optical communication systems in the future.

3.4. Working principle of WOC technologies

Four main types of technologies are available for WOC systems. These technologies differ in the type of transmitter/receiver and the type of radiation.

In visible light (light), or infrared, optical or laser-type radiation communication, light-emitting diodes (LED) or laser diodes (LD) are used as transmitters, and photodetectors (PD) are used as receivers.

Visible Light Communications (VLC) technology uses visible light (VL) as the communication medium. This technology is a communication technology in which the visible spectrum is modulated for data transmission. VLC is considered a short-range communication technology due to the distance that light-emitting diodes (LEDs) can spread their beam (Figure 1). The visible spectrum of the electromagnetic spectrum covers wavelengths between 350 and 800 nm with frequencies ranging from 4.3 x 1014 Hz to 7.5 x 1014 Hz. The current intensity of LEDs is easily modulated compared to other lamps (O'Brien et al., 2008).

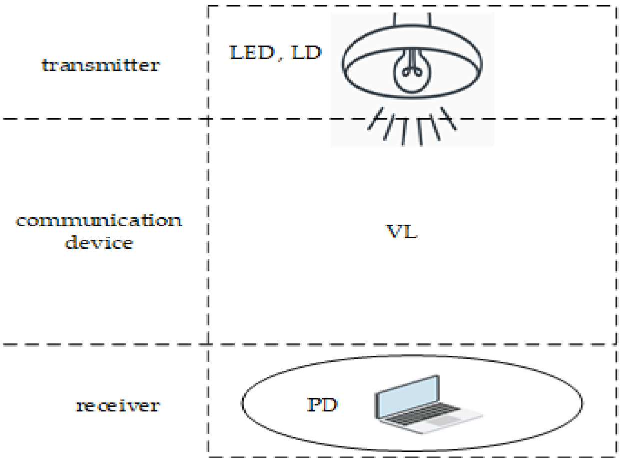

Fig. 1. VLC optical communication

Working principle:

- Light modulation: Information is transmitted by changing the intensity of the light signals emitted by LEDs. The rapid switching on and off of the light source is used to encode binary information;
- Photodetectors: At the receiving end, photodetectors or other light-sensitive devices capture the light signals and convert them back into electrical signals for data processing.

Advantages:

- High data transfer rates: VLC can provide high data transfer rates, especially compared to traditional radio frequency-based wireless technologies.
- Obstacle-free: VLC operates in the visible light spectrum, which is free from obstructions and overloads that are traditional for radio frequency bands.
- Security: VLC signals do not penetrate walls. This provides a level of internal security and limits communication to the physical space illuminated by the light source.

Limitations:

- Line-of-sight: VLC typically requires line-of-sight between the transmitter and receiver, which limits its application in scenarios where there may be obstacles.
- Indoor use: VLC is well suited for use in indoor environments (rooms) where lighting infrastructure can be used to transmit data. However, its application in outdoor environments may be limited because it relies on visible light.
- Sensitivity to lighting conditions: Changes in ambient lighting conditions can affect the performance of VLC systems.

Application area:

- Indoor communication: VLC can be used for wireless communication in indoor environments such as offices, hospitals, and homes where LED lighting is widely used;
- Commercial and service spaces: VLC can be widely used in retail shopping malls for location, indoor navigation, and content-based applications. VLC technology is promising for wireless communication, especially in environments where lighting infrastructure is already available. This technology may further become an important part of the Internet of Things (IoT) and artificial intelligence (Karunatilaka et al., 2015).

Li-Fi (Light Fidelity) is a high-speed wireless optical communication technology that works in both directions. Here, the visible light spectrum is used to transmit data. Li-Fi-enabled devices convert the light beam into an electrical signal, and then back into data. The lamps (LEDs) used in the Li-Fi system are equipped with a chip that modulates the light to transmit data (fig. 2). These chips use the oscillation of light in the optical range to generate binary codes and transmit data.

On the other side, data is received through photodetectors (Hema, 2016).

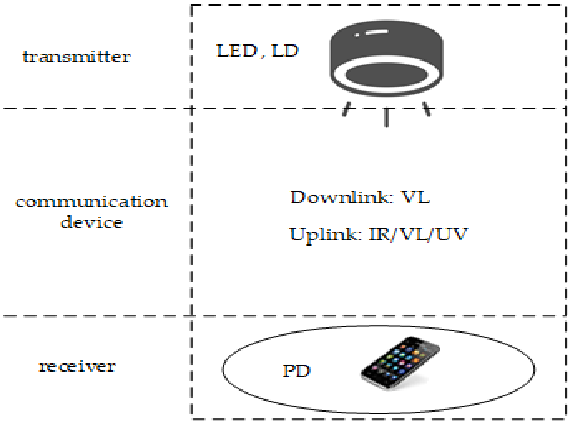

Fig. 2. Li-Fi technology

Some features and advantages of Li-Fi technology may include (Haas et al., 2016):

- High data transfer rates: Li-Fi can provide higher data transfer rates than traditional wireless technologies (Wi-Fi).
- Security: Since light does not penetrate walls, Li-Fi technology can offer more secure solutions for data transmission in indoor spaces.
- Indoor use: Li-Fi can be particularly useful in places where Wi-Fi is overloaded and can suffer from interference. For example, it can be used in offices, medical facilities, and airports where high data transfer rates and security are critical.
- Energy efficiency: Since LEDs are used to transmit data, it can be more energy efficient.
- Limited range: One of the disadvantages of Li-Fi is its limited range. Since Li-Fi signals cannot pass through walls, they are not suitable for some usage scenarios.

Li-Fi technology is still in its development stage and its large-scale real-world application requires additional exploration and standardization. This technology may be an addition to or alternative to available wireless communication technologies in the future.

Optical Camera Communication (OCC) technology is a data transmission method that uses an LED matrix as a transmitter and an image sensor (camera) as a receiver (fig. 3).

OCC provides two-way communication that allows data to be transmitted using light generated by LEDs and sensed by the camera. A standard or sliding shutter video camera is used as the image sensor. Video cameras equipped with a metal-oxide semiconductor integrated with the image sensor make it easy to "take pictures". OCC often uses VL or IR-beam as the communication medium (Elgala et al., 2011).

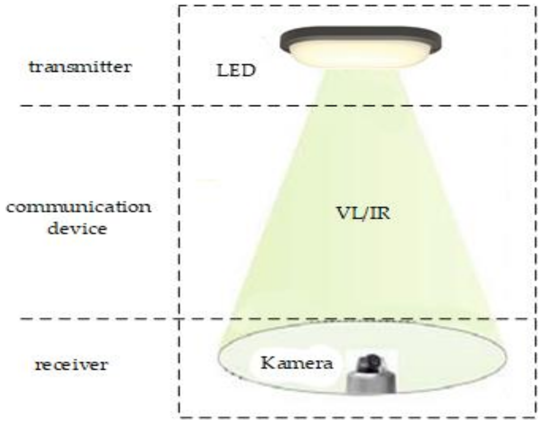

Fig. 3. Optical Camera Communication

This technology has a number of motivating features (Nguyen et al., 2017):

- Wireless communication: OCC allows wireless communication using light signals, which can be useful in certain applications where secure and high-speed communication is required;
- High data transfer rate: OCC can be used to transmit data in real time, including video and audio, providing high data transfer rates;
- Location detection and gesture recognition: OCC technology can be used to determine the location of objects and even recognize gestures. This allows for the creation of interactive systems and applications;
- Use in IoT and indoor communication: OCC can be used in smart homes, indoor communication networks, medical applications, and other areas where wireless optical communication is needed;
- Security: OCC is more reliable in terms of data security, because the light signal is limited to the direct line of sight and is difficult to interfere with from the outside.

OCC technology continues to be developed and researched, and has the potential to be used in various areas where high-speed and secure wireless communication is required.

Free Space Optics (FSO) is a method of transmitting data using light beams in the atmosphere or other free spaces. This technology can be used for wireless data transmission over short and medium distances (fig.4). FSO technology usually uses LDs and PDs as transmitters and receivers (Henniger et al., 2010).

The main features of free space optics technology are as follows (Ding et al., 2023):

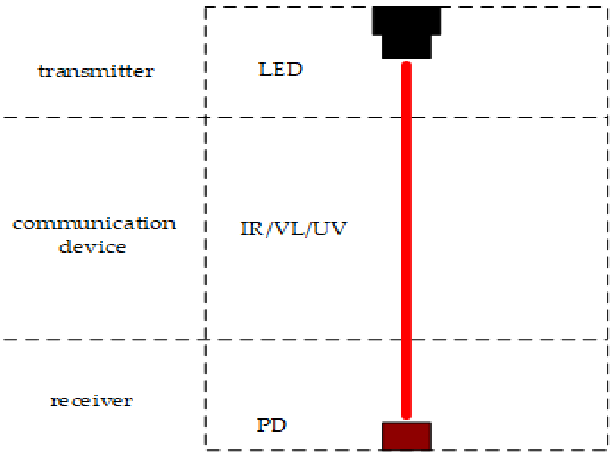

Fig. 4. FSO technology

Using light beams:

FSO works on the basis of laser or LED light sources that generate light beams. The beams received at one point are directed to another point and converted into data. The data transmission process is carried out by changing the intensity of the light in accordance with the information being transmitted. The receiver detects the intensity changes (a device that converts high-frequency vibrations into low-frequency vibrations) and recovers the transmitted information;

Advantages:

- High data transfer rate: FSO can provide very high data transfer rates, which makes it suitable for video surveillance, large file transfers, and high bandwidth requirements;
- Low latency: The latency in an FSO network is usually much lower than in wireless networks based on radio waves;
- Unlicensed use: FSO uses the light spectrum that does not require licensing, which makes its implementation easier.
- Limitations:
- Weather: Weather conditions, including rain, fog, snow, and atmospheric disturbances, can affect the FSO system, reducing the quality of communication;
- Line-of-sight: FSO requires a direct line-of-sight between the transmitter and receiver, which limits its application over long distances and in densely populated urban environments;
- Safety: FSO laser beams can be hazardous to the eyes, and their use requires certain safety precautions.

Application area:

FSO technology can be widely used to build wireless communication networks, especially in cases where high throughput and low latency are required. Examples may include wireless connections between buildings in urban environments, temporary connections at events, and even communication between satellites and the Earth.

FSO is a unique data transmission technology with its own advantages and limitations. Its effectiveness depends on the specific environmental conditions and the requirements for the communication network.

When organizing a radio communication channel, frequencies used range from 3 kHz to 3000 GHz. Part of the radio frequency range (from 3 kHz to 10 GHz) can be used everywhere by existing wireless technologies due to its favorable communication characteristics. This part of the frequency is being exhausted due to its very wide use, while the remaining frequencies cannot meet the requirements of 5G, 6G and IoT networks. Moreover, according to the rules of the International Telecommunication Union (ITU), which allocates frequencies, the allocation and use of the frequency spectrum worldwide is regulated by the ITU and national organizations of various countries.

Currently, work is underway to implement WOC in various scenarios with 5G, such as high-density areas (e.g., airports, stadiums) or environments where radio-frequency signals face problems (e.g., underground systems). WOC can complement existing 5G infrastructures by providing additional traffic or improved transmission conditions. s, WOC may be even more significant, as higher device density and greater traffic are expected. Such networks can be used to provide high-speed and reliable connectivity in densely populated or technology-rich areas.

IoTs require a large number of low-power devices that can transmit and receive data. WOC can be applied to communication between such devices in dense environments where radio frequency communication is challenging. This may include smart homes, smart cities, industrial systems, and many other applications.

WOC technologies have important properties for creating communication channels in 5G, 6G, and IoT networks. WOC can be used for a wide range of applications that implement different types of communication as (Zaman et al., 2019):

- machine-to-machine;
- device-to-device;
- vehicle-to-vehicle;
- interconnection of different infrastructures.

Optical communication allows devices to communicate over distances from a few nanometers to 10,000 km. WOC provides the network with (Zaman et al., 2019):

- high data transfer rate (up to 100 Gbit/s);
- high throughput;
- high security level;
- low energy consumption;
- low cost of infrastructure and devices;
- absence of barriers;
- ease of integration with devices.

Thus, the physical capabilities of WOC technology overcome all the shortcomings of radio communications, and also surpass wireless communications based on radio frequencies in a number of parameters. WOC is a potentially powerful tool for enhancing the capabilities of 5G, 6G and IoT. However, as with any technology, there are limitations and problems, such as transmission range, the possibility of objects or weather conditions blocking signals, and the line-of-sight requirement for some applications.

3.5. Li-Fi-in Physical capabilities and technical characteristics of WOC networks

As an example, Li-Fi technology is explored (table 1.). The data transfer capacity of networks built with Li-Fi currently reaches 1 Gbit/s. The probable bit error (Bit Error Rate, BER) in a Li-Fi network at a distance of about 1 m is 2x10-5 (Petrus, 2014). The range of Li-Fi allows to cover a room with an area of 10-20 m2 with a signal. In a Li-Fi network, data security is further enhanced, as the VL does not penetrate beyond the boundaries of the user's location.

Li-Fi networks can serve an unlimited number of users without negatively affecting each other's signals. Allocation of additional frequency bands is free of charge and does not require a licensing procedure.

Table 1. Comparison of Li-Fi with other technologies

Settings	**VLC**	**Li-Fi**	**OCC**	**FSO**	**4G mobile communication**
Topology type	One-way or two-way	two-way	One-way	One-way or two-way	two-way
Transmission distance	20 m	10 m	60 m	Over 10 000 km	13,4 km
Mobility	+	+	+	-	+
Obstacle level	↓	↓	-	↓	medium
Transmission speed	10 Gb/s LED 100 Gb/s LD	10 Gb/s LED 100 Gb/s LD	55 Mb/s	40,665 Gb/s	100 Gb/s
Security level	↑	↑	↑	↑	medium

The use of energy-saving LED lamps, which are often installed indoors and are installed indoors, allows for a significant reduction in energy costs (fig. 5.). To modernize them and connect them to the Li-Fi network, it is enough to install a few additional components listed below (Ramadhani et al., 2018):

- Decoder;
- Infrared emitter;
- USB interface.

Advantages of systems based on Li-Fi technologies (Khan, 2017):

- Frequency bandwidth - a relatively wide frequency spectrum is used for signal transmission, divided into channels or bands. The larger the bandwidth, the more information can be transmitted;
- High traffic - Li-Fi can provide data transfer rates up to 224 Gbit/s, which makes it ideal for tasks requiring high throughput, such as receiving/transmitting ultra-high-definition video streams, organizing remote workplaces, cloud gaming, virtual reality, etc.;
- The use of this technology is very simple and inexpensive;
- No license is required for its use;
- No radio frequency is used;
- There are no obstacles to the interaction of visible light with electromagnetic waves of other frequencies;

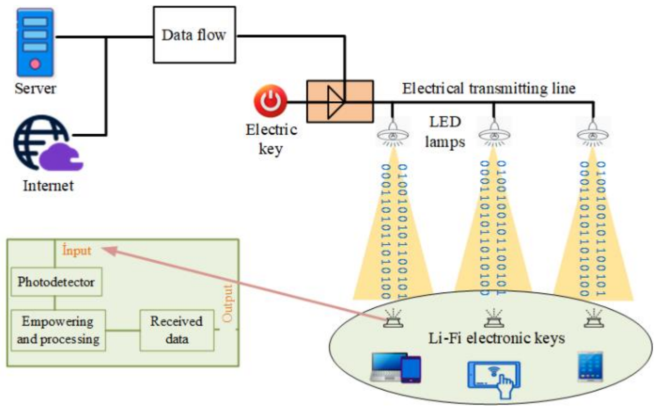

Fig. 5. Li-Fi network architecture

- Disadvantages:
- Direct visibility between the receiver and the transmitter is required;
- Malfunctions and errors may occur when illuminating the photodetector;
- Li-Fi works only within the light cones emitted by the LED

3.6. Application of WOC technologies in various fields

Researchers around the world are working on creating communication networks of the future based on WOC technology.

WOC-based networks can be easily integrated into available infrastructures (Harald, 2014; Petrus, 2014):

- Indoor communication (Li-Fi): WOC can be used for wireless data transmission indoors. Li-Fi technology uses light signals to transmit data, which allows for high-speed and secure wireless networks in offices, stores, airports, and other indoor spaces;
- Medical technology: WOC can be used in medical devices to measure health parameters, transmit image and video data inside the body, and connect medical devices within hospitals;
- Automotive industry: WOC technology can be applied for wireless communication between various systems in cars, such as security, infotainment, and navigation;
- Energy saving: WOC implementation can reduce power consumption compared to wireless technologies that use radio waves to transmit data. This is especially important for battery-powered sensors, IoTs, and mobile devices;
- Virtual reality (VR): WOC can be used for high-speed data transmission between VR devices, enhancing the user's visual and audio sensations;
- Manufacturing and automation: WOC can be applied for wireless data transmission between various devices and automation systems in manufacturing areas;
- Ecologically sensitive areas: In some cases where the use of radio frequencies is prohibited or not recommended (for example, near radio telescopes or in ecologically sensitive areas), WOC can provide an effective communication method;
- Highways: It can be used in traffic control systems to connect computers and mobile devices to each other. Based on the WOC base, a universal traffic management system is being developed that provides information about the speed of cars on roads and highways (The uplink visible light communication beacon system for universal traffic management). This system uses an LED as a transmitter and several PDs with lenses as receivers (Petrus, 2014; Arnonet al., 2012);
- Air transport: Li-Fi networks can be used to transmit video signals to personal monitors installed in front of passengers in the cabin of passenger aircraft. This allows for the removal of several kilometers of cables and a reduction in the weight of the aircraft by more than 100 kg (Petrus, 2014).

4. Discussion

Wireless optical communication (WOC) is a rapidly developing technology. This technology provides access to the unlicensed range of the electromagnetic (EM) spectrum. In addition, it has a number of advantages that make it a suitable wireless technology for future 5G/6G networks and IoT systems.

Thus, the use of WOC technologies for the construction of next-generation mobile networks will solve the problems inherent in radio frequency-based communication systems. WOC will provide these systems with efficient communication channels for the installation of 5G/6G and IoT networks.

By applying innovative approaches to solving problems, technological development and integration methods, wireless optical communication networks can be made more powerful and effective. Research should be continued to study and develop the problems and solutions in this field in more depth.

5. Conclusion

Currently, 5G networks have been launched in some countries and are being developed rapidly. According to forecasts, 6G communication is predicted to be launched between 2027-2030. Systems based on radio frequencies cannot meet the high requirements of the next generation 5G/6G and IoT networks.

Basically, it is difficult for 5G/6G and IoT networks to achieve their goals in the tactical internet. The most important and complex issue for 5G communication systems is to ensure high traffic, mass connectivity, low latency, high security, low energy consumption, high QoS and very reliable connection. Systems based on radio waves alone will be unable to meet the requirements of future 5G/6G and IoT networks. WOC technologies can be the best complementary solution for networks based on radio waves. The coexistence of radio waves and wireless optical systems can enable such networks to achieve their goals. This research showed the use of WOC (VLC, Li-Fi, OCC and FSO) technologies to be an effective solution for the successful implementation of future 5G/6G and IoT networks. In this regard, a brief explanation of the characteristics of 5G/6G, IoT systems and WOC technologies was given here.

Wireless optical communication technologies have great potential to meet the requirements of 5G and 6G networks, but issues such as environmental conditions, energy efficiency, security and network density make the widespread application of these technologies difficult.

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