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TECHNICAL FEATURES OF BUILDING A LI-FI NETWORK USING SDN MANAGEMENT METHODS

Oleksandr Romanov
Professor
Institute of Telecommunication Systems
National Technical University of Ukraine
“Igor Sikorsky Kyiv Polytechnic Institute”, Kyiv, Ukraine
https://orcid.org/0000-0002-8683-3286, e-mail: a_i_romanov@ukr.net
Hrigorii Burlaka
Postgraduate student
Institute of Telecommunication Systems
National Technical University of Ukraine
“Igor Sikorsky Kyiv Polytechnic Institute”, Kyiv, Ukraine
https://orcid.org/0000-0001-7945-6948, e-mail: grisaburlaka0@gmail.com
Oleksandr Berestovenko
Postgraduate student
Institute of Telecommunication Systems
National Technical University of Ukraine
“Igor Sikorsky Kyiv Polytechnic Institute”, Kyiv, Ukraine
https://orcid.org/0000-0003-4887-4674, e-mail: berestok6797@gmail.com
Oleksandr Pidpaly
Postgraduate student
Institute of Telecommunication Systems
National Technical University of Ukraine
“Igor Sikorsky Kyiv Polytechnic Institute”, Kyiv, Ukraine
https://orcid.org/0009-0007-6852-7959, e-mail: sashapidpalyi@gmail.com

Abstract. The construction of LI-FI wireless access networks using open source platforms offers very good prospects for communication operators. At the same time, it is necessary to develop system models and describe management methods. For this purpose, the paper proposes to use a centralized management system based on SDN principles. Having complete information about the state of network elements allows you to ensure optimal use of network resources, increase throughput and quality of service. The analysis of the principles of building a LI-FI office network using the management level based on SDN principles to reduce interference in cells, increase throughput and quality of service has been made. The analysis of well-known publications devoted to the methods of construction and management of load flows in LI-FI networks using centralized control systems, reducing the level of interference in cells due to the optimal use of network resources has been carried out. Based on the analysis of the LI-FI network operation process using centralized management systems, limitations are determined and recommendations are developed regarding the order of user service at access points. Building an access network based on Li-Fi technology is a very promising direction for solving the problems of existing wireless access networks based on radio frequency technologies. To manage such a network, it is advisable to use open source SDN platforms, and, in particular, the ONOS operating system. The proposed solutions require the development of mathematical models and methods for the optimal solution of control problems in different operating conditions.

Keywords: OWC, Li-Fi, SDN, ONOS, management methods, PoE.

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Introduction

Currently, there is a sharp increase in traffic in wireless access networks of systems for various purposes. These are Industry 4.0, Internet of Things (IoT) systems and others. For example, it is predicted that by the end of 2022 the IoT market will have 20-30 billion active hosts (Chowdhury *et al*., 2018). Studies show that the generated traffic in wireless access networks has been growing exponentially in recent years. At the same time, a critical task is to ensure the specified throughput and quality of service (QoS) indicators for users in the system (Haas, 2018; Romanov *et al*., 2020).

One of the main components that determine the level and quality of the services provided is a wireless access telecommunications system that ensures the interaction of all elements. In this area, a number of shortcomings can be noted that may slow down the development of systems and the provision of modern services in the near future. The main ones are (Wang *et al*., 2022; Romanov, & Miklaiv, 2021; Huang *et al*., 2022).

1. Limited capabilities of the used wireless access technologies in terms of throughput and quality of service.
2. Construction of existing telecommunication networks based on specialized monolithic network elements, such as switches, routers, which requires large time and material costs when introducing new technologies.
3. Low level of intelligence of telecommunications network management systems.

Let us briefly analyze the impact of these shortcomings and ways to overcome them.

Currently, wireless access is mainly carried out using radio frequency technologies such as Wi-Fi, Bluetooth, RFID. And the leader in this area is WiFi technology. However, radio technologies in access networks are already at the limit of their capabilities in terms of throughput and quality of service. Therefore, further development requires the search for new, more efficient wireless access technologies. As the analysis of modern literature shows, one of the directions for solving this problem can be considered the use of the optical frequency spectrum for building future wireless access networks with high density and throughput.

The second drawback is related to the fact that the existing networks were created on the basis of specific software and hardware platforms from different manufacturers. This has led to low flexibility, poor scalability and dependence of telecom operators on equipment vendors. The solution to this problem can be the use of SDN technology when building networks. This allows you to significantly increase the efficiency of their functioning due to the centralization of management; virtualization of functions of network elements, applications and services; separation of hardware and software functions. With this approach, operators have the opportunity to independently develop applications and implement them as an addition to the basic software. This allows you to significantly speed up the process of providing new modern services to network users.

The third disadvantage associated with the low level of intelligence of control systems requires the development of new models and methods for solving control problems that allow optimizing the efficiency of using network infrastructure resources and network equipment. The principle of centralized management, embedded in the SDN network management system, has ample opportunities to improve the efficiency of the network.

However, in order to use these opportunities, it is necessary to develop models and methods for solving problems of intelligent control. At the same time, special attention should be paid to the methods of collecting initial data, the timeliness of their submission to the authorities and the assessment of their reliability. In addition, indicators reflecting the actual parameters of the network should be used as initial data:

It should be noted that in order to solve these problems, the hardware and software structure of the network, the composition of the functional blocks of the network elements,

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their purpose and functions should be determined. It is also necessary to describe the relationship of elements in the process of solving problems in various network operating conditions.

Materials and methods

One of the possible ways to increase the throughput and quality of service of wireless access systems is to use Li-Fi (Light Fidelity) technology, where instead of radio frequencies, VLC (Visible Light Communication) visible light spectrum waves are used for data transmission.

Although the practical use of the technology is still in its early stages, much research is being done to achieve high data rates and reliable delivery to users. In this case, ordinary light emitting diode (LED) lamps can be used as devices for transmitting and receiving light waves. This approach makes it possible to use the lighting infrastructure as a ready-made telecommunications environment.

Significant results in the practical application of Li-Fi technology have been achieved in the field of building ITS (Intelligent Transportation Systems). Here solutions are obtained for the use of lighting infrastructure, car headlights and traffic lights for communication and compliance with road safety requirements. In addition, there are patents for the use of Li-Fi technology in aircraft, offices, and large shopping centers. The use of Li-Fi technology in wireless access networks provides significant advantages over other technologies. The main ones are:

1) Availability. Li-Fi uses LEDs as a data carrier, which allows us to use the lighting system as a ready-made data network. This easy accessibility results in significant cost savings.

2) Capacity. The available radio frequency spectrum for wireless communications can be expanded by a factor of 10,000 by using the visible light spectrum. It can be street light, LED table lamp and other light sources.

3) Security. When transmitting with Li-Fi technology, you can ensure security by simply blocking the light, thus allowing for an easy implementation of security, and therefore a more secure way of transmitting data.

4) An environmentally friendly system that reduces health risks. RF signals are carcinogenic and may pose a threat to human health, while visible light is safe for your life.

5) Ability to use existing infrastructure. For Li-Fi, we can use existing LED light sources as hotspots, thus reducing the cost of infrastructure development.

6) High rates of energy saving and energy efficiency:

Results and discussion

In modern wireless communications, a large amount of energy is spent on infrastructure and its maintenance. For example, a lot of energy is spent on cooling base stations and keeping them in working order. Whereas when using LiFi technology, it is enough to have a 60-watt LED light bulb that can be used as an access point.

Thus, the LiFi technology itself can significantly improve the efficiency of the access network. We can get further efficiency gains by implementing advances in SDN technology. Especially the management principles embedded in this technology. Today, research is underway and proposals are being developed for the practical implementation of this technology within the framework of a number of projects. These projects cover the creation of the next generation broadband access infrastructure, the construction of a service platform (services platform) for the provision of services, a platform for building SD-RAN and Core RAN networks of 5G / 6G mobile operators, a platform for building basic fixed networks, SD-FABRIK and other important telecommunications industries. Representatives of the Open

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Networking Foundation (ONF) consortium make the greatest contribution to the development of this area. ONF is at the head of all projects to build SDN and is engaged in accelerating the processes of their practical implementation (Chowdhury *et al*., 2018).

A number of documents describing the principles of construction and operation of SDN networks have been published. In (Romanov *et al*., 2020; Wang *et al*., 2022; Romanov, & Miklaiv, 2021; Huang *et al*., 2022) general requirements, system approaches and generalized architecture of SDN networks are considered. The papers (Haas, 2018; Xu *et al*., 2017; Romanov *et al*., 2018; ONF TR-539, 2016) consider the tasks and features of the protocols used to solve various problems in SDN networks. The works (Zeng *et al*., 2017; Geldard *et al*., 2022; Alowa *et al*., 2020) describe the features of building SDN network elements and the order of their interaction in the process of servicing information flows. In (ONF TR-525, 2015; Das, 2020; Romanov *et al*. Principles of Building, 2022; Romanov *et al*. SDN network modeling, 2022; Romanov *et al*. Construction, 2021), the principles of building an optical transport network are considered and recommendations are given to ensure the safety of their operation. The most complete and systematized material is presented in (Romanov *et al*. Mathematical description, 2021 Phemius *et al*., 2013). Articles (Lam *et al*., 2016; Comer *et al*., 2019) explore various aspects of servicing information flows and focus on the need to meet network security requirements.

The most complex tasks in SDN networks are faced by the control layer, which acts as a centralized control system. Consider how the structure of the LiFi transmission path will change when using the management principles adopted in SDN networks.

Figure 1 shows a possible structure of the signal transmission path in a wireless Li-Fi network using the SDN control plane. Signal transmission through the Li-Fi network path is based on VLC (Visible Light Communication) where light acts as the communication medium. The light source is a Led Lamp controlled by a Lamp Driver. The data sources can be the Server or the Internet, which are connected via an SDN switch. The Lamp Driver adjusts the blinking speed of the LEDs and controls the modulation of the transmitted signals. Modulated signals control the speed at which light flickers when transmitting digital data (values 0 and 1). The data emitted by the LED is received by a light-sensitive device called a photodetector, which processes and amplifies the signal. Next, the light signals are converted into digital signals. Thus, the received signals are converted to the form in which they came from the information source.

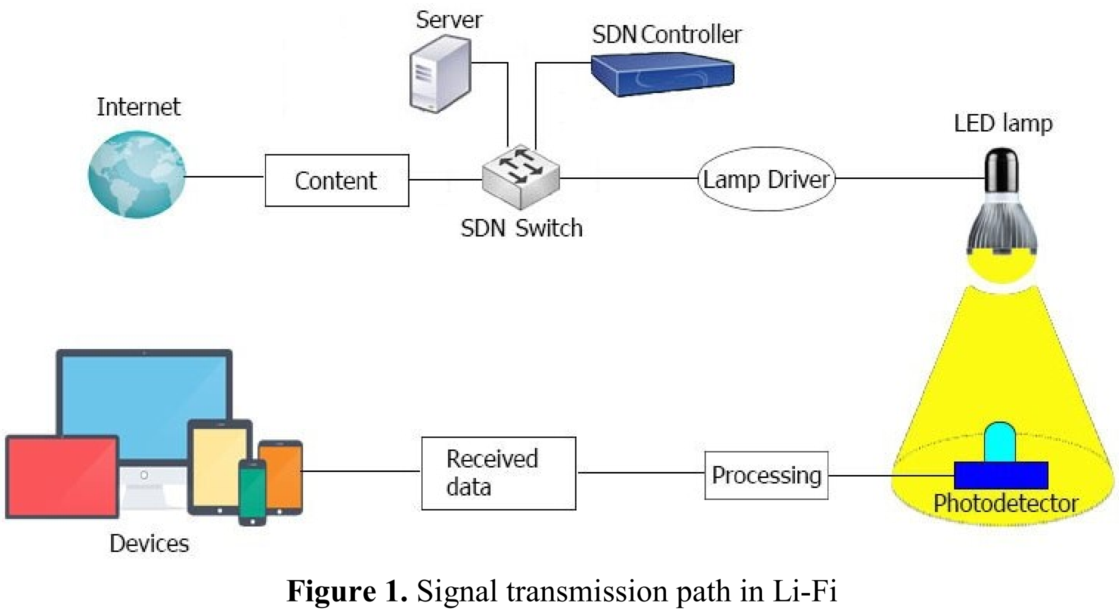

Figure 1. Signal transmission path in Li-Fi

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Li-Fi can provide simultaneous network access to many users because it is a broadband wireless technology. In Li-Fi technology, an optical space division multiple access (SDMA) scheme can be implemented using transmitters with an angular separation. Compared to optical time division multiple access (TDMA), SDMA can achieve a tenfold increase in throughput in a Li-Fi network. Using OFDM provides a simpler multiple access technique, that is, orthogonal frequency division multiple access (OFDMA), in which users are served and separated by a plurality of orthogonal signal subcarriers.

In addition, the performance of the Li-Fi network path can be improved by using NOMA non-orthogonal multiple access. Different from conventional OFDMA technologies, NOMA can serve a much larger number of users by allocating non-orthogonal frequency resources. It is possible to use other modulation methods.

As a rule, all studies of Li-Fi networks are focused on the transmission path from the LED to the photodetector. However, for a comprehensive study of the system, it is necessary to consider the service process in all elements of the network. Let's consider a possible option for building a campus Li-Fi optical access network with SDN elements, which is shown in Figure 2.

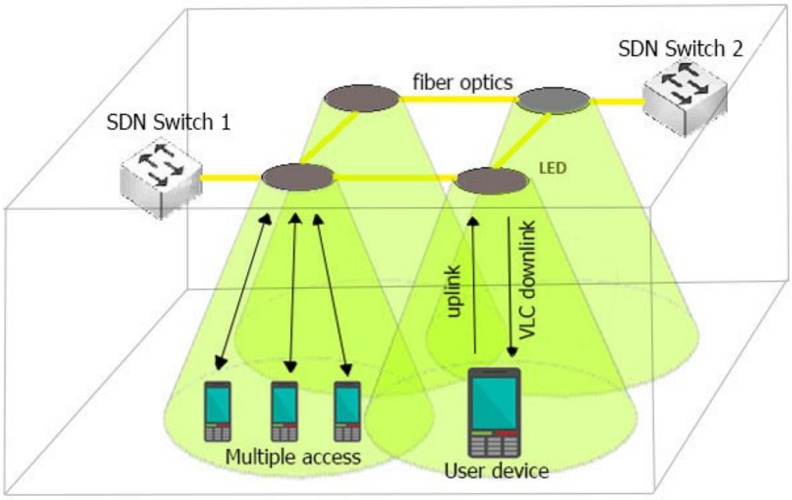

Figure 2. Variant campus Li-Fi network with SDN elements

The Li-Fi network shown in Figure 2 includes multiple access points for uplink, downlink, and reverse link connections. In addition, the system provides functions for transmitting and receiving information, support for user mobility and the possibility of flexible access to resources. To do this, the network has the following elements:

1. LED lamp that provides wireless information transmission using VLC.
2. Fiber optics - lines connecting LED lamps, switches and other network elements.
3. SDN Switch, - switches that provide the establishment of a data transfer path between access points.
4. User device - mobile devices of users that connect to an access point and then to the global network
5. Uplink. An uplink for transmitting data from a user's mobile device to a network. It provides a request for various services, confirmation of data receipt, transmission of information about the state of the channel.
6. VLC downlink. Downlink for downloading data from the network.
7. Interaction lines between access points, network switches and other network elements.

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Access points (APs) form ultra-small cell networks to provide high-density wireless communications services to mobile users. The Li-Fi network must support data service when users move through different light coverage regions. In a Li-Fi network, a two-way communication is established between an AP and a UE, making it possible for the AP to serve multiple users at the same time. In addition, the backhaul links between access points and the network gateway are essential to enable cooperation between access points and establish communication with the external network. These feedbacks can be implemented by optical fiber, Power-over-Ethernet network or power lines. The downlink Li-Fi is powered by the existing LED lighting system. This is due to the fact that LED lighting is becoming more and more popular. In addition, transmission at a rate of several tens of Gbit/s through LEDs was demonstrated.

On a Li-Fi network, an uplink connection is required to send requests for certain content, send acknowledgments, send Channel State Information (CSI) and download files, and enable voice and video calls. The principle of information exchange in the network is as follows. The user connects to a specific LiFi hotspot in the same way as a WiFi hotspot. Thanks to this, he gains access to the network. It can download a file on the downlink, or vice versa upload information on the uplink. The user in the process of moving changes his access point. Switching is performed automatically without breaking the connection. The interconnection of network elements can be provided by a fiber optic line or via a power supply network. If you want to establish communication between access points in different rooms, SDN Switches are used. Since the use of visible light in the uplink may cause distraction to the mobile user, the use of infrared is considered to be the most appropriate for this link direction. This also has the added benefit that the uplink and downlink do not interfere with each other, and simultaneous communication with different entities can be established.

It should be noted that despite the presence of several publications in the field of research on the transmission of information on the uplink based on infrared radiation, further comprehensive investigations are required in this direction. In addition, radio based communication technologies such as Bluetooth, ZigBee and especially Wi-Fi can also be considered. There are publications which state that an RF/VLC hybrid communication system with a downlink-only VLC is capable of offloading a significant amount of data traffic while still having low latency.

The process of network functioning is quite complicated. Users move around the room. This changes the angles of transmission and reception of signals, the distance between the elements of the system, LED service areas. At the same time, it is necessary to ensure the requirements for the level of lighting at each point of the room. Therefore, to address these issues in the network, it is proposed to use the principles of SDN management. Today, the ONF consortium develops a number of open source platforms. Therefore, an SDN controller can be recommended as a centralized LiFi network management device. As a basis, you can take a controller designed to control the data center. Then the structure of the LI-FI network will look like shown in Figure 3.

Building a LiFi network using the SDN control plane requires more research. It is necessary to provide a system of multiple user access and interference coordination in public channels. Consider use cases: horizontal and vertical handover. At the same time, in case of horizontal handover, provide for the possibility of changing the serving access point, for example, to radio access technology. Vertical handoff may refer to a change in a serving AP belonging to a different radio or optical device. For example, mobile users can be transferred from a Li-Fi hotspot to a Wi-Fi hotspot when none of the Li-Fi hotspots can offer a reliable link or the user's speed is too high. At the same time, the residence time in the cell is too short

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to establish a high quality of communication. When the user slows down and enters the coverage of a lightly loaded Li-Fi hotspot, it may be better to transfer that Li-Fi hotspot to a lighter Wi-Fi network for more efficient operation (for example, to ensure less packet collisions).

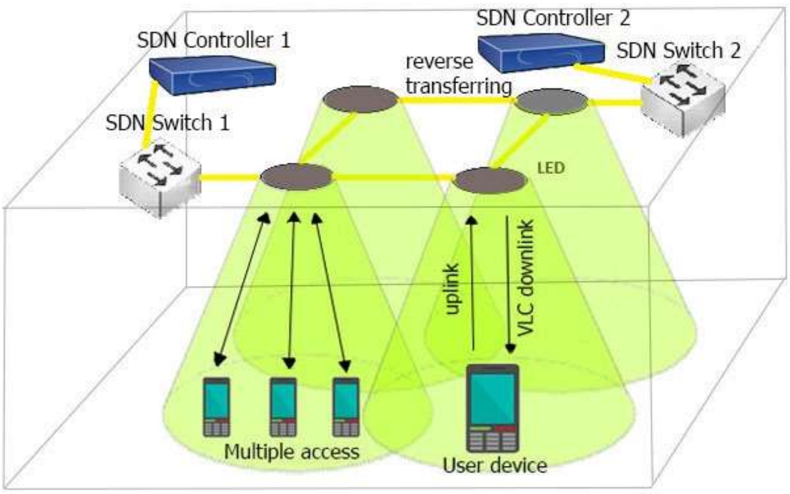

Figure 3. LiFi campus network using SDN controllers

It should be borne in mind that the efficiency of such a complex network will largely depend on the level of intelligence of the controller. At the same time, the main element of the controller is ONOS. A possible version of the ONOS architecture is shown in Figure 4.

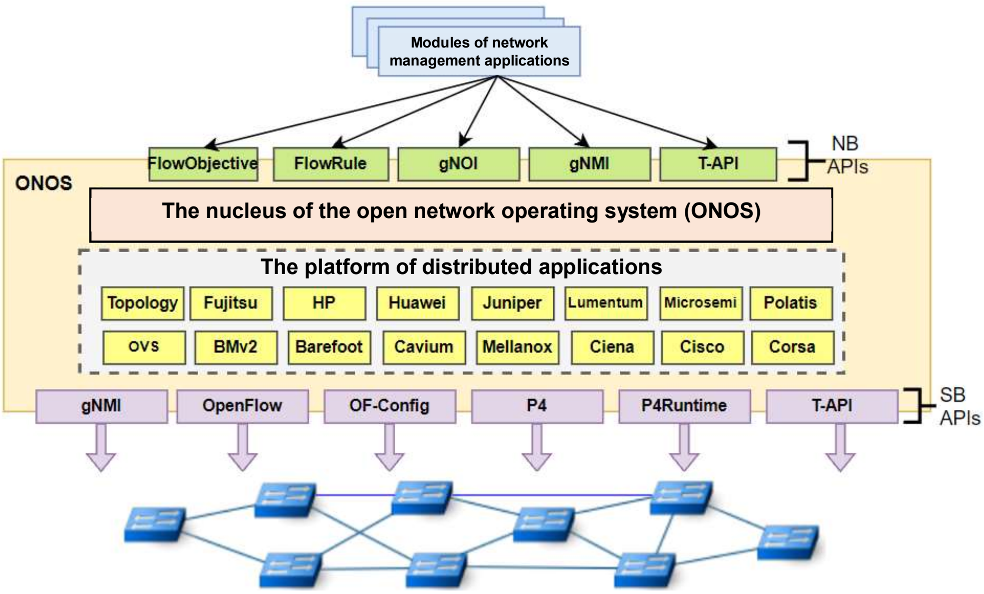

Figure 4. ONOS architecture

As can be seen from Figure 4, the ONOS design is modular. In this case, a particular deployment is designed to include the necessary subset of modules.

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Three features should be noted.

The first feature is that the horizontal plane of the NBI is quite large. Any access to the underlying equipment, whether it is a control program or a human operator, is carried out through ONOS. This means that the totality of all northern APIs should be sufficient to set up, operate and manage the network. For example, NBI includes gNMI and gNOI for setup and operations, respectively. This also means that NBI includes a topology API, which management applications use to get information about changes in the underlying network state (for example, ports go up and down), as well as a Flow Objective API, which is used to manage underlying switches.

It should be noted that there is a wide range of applications that run directly on ONOS. These applications may have a graphical interface that can be used to monitor network status. Applications may have a command line interface that operators can use to issue directives. These issues are discussed in more detail in (Romanov *et al*., 2020; Zeng *et al*., 2017; Das *et al*., 2020).

Conclusions

1. Building an optical access network based on Li-Fi technology using SDN management methods is a very promising direction for solving the problems of existing wireless access networks based on radio frequency technologies.
2. Comparative characteristics of performance indicators of optical access networks with wireless access networks based on radio frequency technologies shows that LiFi has advantages in most performance indicators.
3. Given that wireless access based on radio technologies today has a large coverage, these networks will be used together during the transition phase. At the same time, the priority in the use of a particular technology will be determined by the network operating conditions.
4. For management, it is advisable to use open source platforms for SDN networks, and, in particular, ONOS, which are now being actively developed by the ONF community.
5. For the further development of this direction, it is necessary to develop mathematical models and methods for optimally solving control problems under different operating conditions, which will later become software modules at the application level.

Acknowledgements

None.

Conflict of Interest

None.

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ТЕХНІЧНІ ОСОБЛИВОСТІ ПОБУДОВИ LI-FI МЕРЕЖІ ЗА ДОПОМОГОЮ МЕТОДІВ КЕРУВАННЯ SDN

О. І. Романов
Професор
Інститут телекомунікаційних систем
НТУУ «КПІ ім. Ігоря Сікорського», Київ, Україна
https://orcid.org/0000-0002-8683-3286, e-mail: a_i_romanov@ukr.net
Г. Ю. Бурлака
Аспірант
Інститут телекомунікаційних систем
НТУУ «КПІ ім. Ігоря Сікорського», Київ, Україна
https://orcid.org/0000-0001-7945-6948, e-mail: grisaburlaka0@gmail.com
О. О. Берестовенко
Аспірант
Інститут телекомунікаційних систем
НТУУ «КПІ ім. Ігоря Сікорського», Київ, Україна
https://orcid.org/0000-0003-4887-4674, e-mail: berestok6797@gmail.com
О. І. Підпалий
Аспірант
Інститут телекомунікаційних систем
НТУУ «КПІ ім. Ігоря Сікорського», Київ, Україна
https://orcid.org/0009-0007-6852-7959, e-mail: sashapidpalyi@gmail.com

Анотація. Побудова мереж бездротового доступу Li-Fi з використанням платформ із відкритим кодом дає дуже добрі перспективи операторам зв'язку. При цьому необхідні розробка моделей системи і опис методів управління. Для цього в роботі пропонується використовувати централізовану систему управління на принципах SDN. Наявність повної інформації про стан елементів мережі дозволяє забезпечити оптимальне використання мережевого ресурсу, підвищити пропускну здатність та якість обслуговування.

Зроблено аналіз принципів побудови офісної мережі Li-Fi з використанням рівня управління на принципах SDN для зменшення перешкод у стільниках, підвищення пропускної здатності та якості обслуговування.

Проведено аналіз відомих публікацій, присвячених методам побудови та управління потоками навантаження в мережах Li-Fi з використанням систем централізованого управління, зменшення рівня перешкод у стільниках за рахунок оптимального використання мережевого ресурсу. Завдяки технології Li-Fi значно підвищується ефективність мережі доступу; ще більше підвищити ефективність мережі можна, впровадивши принципи керування, закладені у технології SDN. Найскладніші завдання в мережах SDN стоять перед рівнем управління, який діє як централізована система керування. Розглянуто, як зміниться структура тракту передачі Li-Fi при використанні принципів управління, прийнятих у мережах SDN.

На базі аналізу процесу функціонування мереж Li-Fi з використанням систем централізованого управління визначено обмеження та розроблено рекомендації щодо порядку обслуговування користувачів у точках доступу.

Побудова мережі доступу на базі технології Li-Fi є дуже перспективним напрямом вирішення проблем існуючих бездротових мереж на базі радіочастотних технологій. Для управління такою мережею доцільно використовувати платформи з відкритим кодом мереж SDN і, зокрема, операційну систему ONOS. Запропоновані рішення вимагають розробки математичних моделей та методів оптимального вирішення завдань управління у різних умовах функціонування.

Ключові слова: OWC, Li-Fi, SDN, ONOS, методи управління, PoE.

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