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METHOD OF DYNAMIC RECONFIGURATION OF SOFTWARE-DEFINED NETWORKS

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A method of using random geometric intersection graphs for generating the topology of software-defined networks when using wireless communication methods is proposed. The influence of the level of use of the data transmission channel on the qualitative characteristics of data transmission was studied. The use of different configurations of the IEEE 802.11 protocol was considered and the speed and delay at different levels of WiFi channel load were compared.

Key words: random graph, topology generation, SDN.

1. Introduction

Software-defined networks are gaining popularity due to the possibilities of more efficient management of heterogeneous networks. The reason is a large number of network devices, which have differences in the management and construction of large computer networks. The lack of standardization of network device operating systems presents a challenge in configuring, collecting telemetry, and further managing each individual network device.

The use of SDN (Software defined network) technology provides the ability to solve routine tasks on devices that support the Openflow protocol. The protocol makes it possible to build networks using equipment from different vendors, which may differ in improved properties in certain usage scenarios.

The dimensionality of networks and the globalization of businesses are increasing, so the needs for effective network management and increasing the speed and reliability of data transmission are becoming more urgent. The main task of the efficient operation of the devices is to increase the fault tolerance of the network and improve its speed characteristics. The spread of remote work requires the adaptation of infrastructure components in enterprises to safely and quickly reconfigure according to business needs. Therefore, the development of new methods for reconfiguring the topology of computer networks and improving the characteristics of data transmission are among the most urgent problems of the industry.

2. Literature review and problem statement

One of the key components of SDN networks is the controller, which is at the management level (Northbound) and performs configuration, monitoring and management of end devices (Southbound). Different controller implementations have different characteristics.

The study [1] examines the performance of the network in view of the use and comparison of different types of controllers. The authors stated that the OpenDayLight and Floodlight controllers have a higher bandwidth compared to the Open Network Operating System (ONOS), NOX, POX, RYU controllers. However, compared to other controllers, ONOS has a more flexible API and allows implementing different routing and traffic processing algorithms. Though, the authors do not consider the issue of improving efficiency by changing the connections between Southbound devices, or comparing the operating systems (OS) of the devices themselves.

Farhan et al. [2] describe the growth trends in the amount of encrypted traffic on the Internet in connection with the spread of automated and free certificate issuance services for encryption. The share of free LetsEncrypt certificates has increased and reached 90% of the market as of 2021. With the advent of such services, almost all services work using the HyperText Transfer Protocol Secure (HTTPS) protocol. These circumstances create certain difficulties in using classic methods of shaping or redirecting traffic.

Research [3] shows that DPI (Deep Packet Inspection) technology is used for effective classification of encrypted traffic, which, unlike classic firewalls, analyzes not only packet headers, but also the payload starting from the channel level of the Open System Interconnection (OSI) network model. Deri et al. [3] compared different traffic recognition algorithms and found that the nDPI library recognizes different types of traffic with greater accuracy than the Protocol and Application Classification Engine (PACE), Libprotoident and the Universitat Politecnica de Catalunya Machine Learning Algorithm (UPC MLA). This approach provides the ability to configure Quality of Service (QoS) more efficiently, because the uneven loading of communication channels caused by the inability to identify the type of traffic and determine its priority is a widespread problem in SDN networks [4].

A large amount of research is devoted to increasing the fault tolerance of wireless SDN networks and improving their characteristics. In the researches Li et al. [5], the problem of increasing the number of IoT devices in the field of medicine, which are used to read indicators of vital functions, is considered, there was a need for low delay in the transmission of information for critical patients using orthogonal multiplexing.

The work [6] presents an algorithm that describes the effective use of Overlapping Basic Service Set/Preamble Detection (OBSS/PD) threshold levels. This is a continuation of the development of Dynamic Frequency Selection (DFS), which allows analyzing the degree of channel congestion and selecting the least busy ones and adapting the channel width. Also, the Institute of Electrical and Electronics Engineers (IEEE) 802.11h standard introduced Transmit Power Control (TPC), which allows reducing the transmitter power to reduce interference with other networks.

The latest versions of the 802.11 protocol solve one of the main problems of wireless communication - signal interference. Since the first versions of the protocol (802.11 b, g, n) had only 3 non-overlapping channels out of 13 available with a width of 22 MHz. The development of frequency scanning in which access points operate led to the emergence of the IEEE 802.11bh protocol, which aims to expand the capabilities of room sensing using Wireless Fidelity (Wi-Fi) technology [7]. This approach will allow adding scenarios for the use of wireless communication in modern Internet of Things (IoT) systems.

The considered literary sources allow us to state that it is reasonable to conduct a study of improving the fault tolerance of Southbound connections of devices in a wireless SDN network and the use of different operating modes of the IEEE 802.11 protocol.

3. The aim and objectives of the study

The purpose of this study is to develop a method of reconfiguration of software-defined wireless networks to increase network fault tolerance and improve data transmission characteristics. This will make it possible to continue data transmission and prevent the loss of information when certain communication channels are lost, or they are overloaded by other networks or means of influence.

The object of research is the process of generating the topology of a software-defined network using graph theory, namely, random geometric intersection graphs. Also, the object of the study is the impact of the wireless communication channel load on the quality characteristics of the data transmission channels.

To achieve the goal, the following tasks are set:

– to develop a method for generating the topology of the SDN network using a random geometric intersection graph.

– to determine the influence of the wireless channel load indicator on the data transfer rate. Conduct research with different types of access point settings in IEEE 802.11 n, ac, ax protocols with different MIMO modes.

4. Methods of reconfiguration of software-defined wireless networks

4.1. A method for generating the topology of wireless SDN networks using random geometric intersection graphs

One of the fundamental tasks of SDN networks is the generation of network topology for further use in the construction of data transmission routes between different points in the network. For an effective solution to this problem, it is suggested to consider the SDN network as a graph, where network devices are vertices of the graph, and network connections are edges. Since the construction of wireless SDN networks is considered in this work, the vertices of the graph do not have constant connections between each other and can be reconfigured over time due to a change in certain parameters of communication channels, their degradation or a decrease in quality characteristics. During the study of the optimal choice of SDN network topology generation using different graphs, the following types of graphs were considered: Erdős–Rényi graph, random geometric graph, and random geometric intersection graph. Since in SDN networks devices belong to managers (Northbound) and subordinates (Southbound), there is a certain need for clustering. The Erdős–Rényi graph or binomial graph was introduced in 1959 at the same time as Edgar Hilbert's graph [8]. In such a graph, connections between two vertices have probability $p \in (0,1)$ [9]. The problem of using this type of graph in an SDN network is its low clustering coefficient and at a certain level of probability, a large number of vertices are isolated. An example of such a graph is shown in Figure 1.

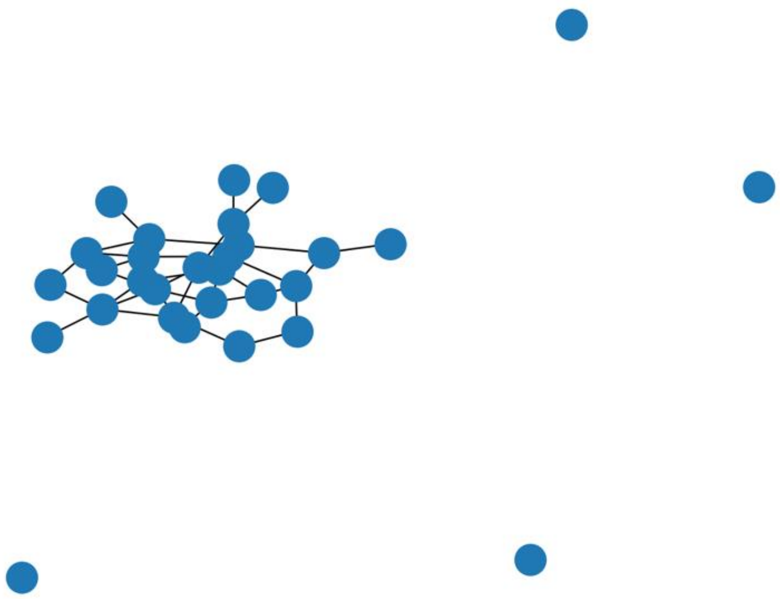


Fig. 1 Graph Erdős–Rényi (n = 30, p = 0.2)

Thus, certain vertices may have no connection with others at all, which is unacceptable, and the position of the vertex relative to others is not taken into account when constructing connections.

Unlike the Erdős–Rényi graph, the random geometric graph has a much smaller number of isolated vertices and takes into account the locations of the vertices when building connections. The clustering coefficient for such a graph is determined by the formula (1) [10]:

$$C_d = \begin{cases} 1 - H_d(1) & \text{even } d \\ \frac{3}{2} - H_d\left(\frac{1}{2}\right) & \text{odd } d \end{cases}, \tag{1}$$

where,

$$H_d(x) = \frac{1}{\sqrt{\pi}} \sum_{i=x}^{\frac{d}{2}} \frac{\Gamma(i)}{\Gamma\left(i+\frac{1}{2}\right)} \left(\frac{3}{4}\right)^{i+\frac{1}{2}}. \tag{2}$$

Thus, the clustering coefficient of the graph depends only on the dimension of the graph and is a constant value. The graph of the dependence of the clustering coefficient on the dimension of the graph is shown in Figure 2 [10].

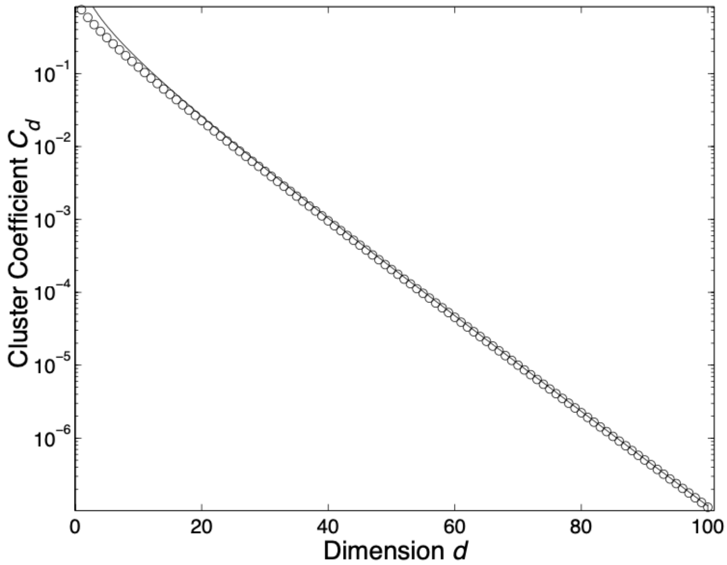


Fig. 2 Graph of dependence of clustering on dimension
for random geometric graphs of intersections

An example of a random geometric graph is shown in Figure 3. In this graph, there is a large number of local clusters connected by vertices with a lower degree.

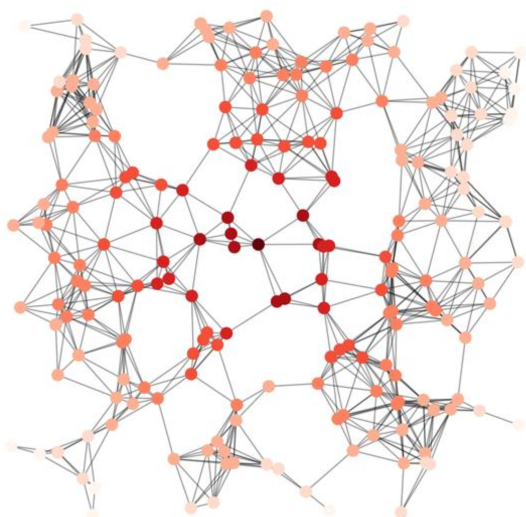


Fig. 3 Random geometric graph (n = 200, p = 0.125)

When using this type of graph in SDN networks, switches can be represented as vertices of the graph and connected according to the random geometric graph algorithm. However, in this case, there is no clear correspondence of the graph clusters to the management level, which controls the Southbound switches.

A random geometric graph of intersections can completely cover the need to generate an SDN network topology. This is a type of graph that is a combination of two types of graphs: a random geometric graph and a graph of intersections [11]. In this case, you can display Southbound switches as a set of vertices V and Northbound control routers as a set of vertices U. The next step is to distribute the vertices in the given space according to the Poisson distribution. After that, primary connections of switches with routers are formed by analogy with random geometric graphs. The next stage is the formation of connections between the vertices of two v, if they both have connections with the corresponding vertex u by analogy with the graph of intersections. In this way, clustering of switches occurs mainly due to the geometric location relative to routers. This allows to have a large number of alternative routes to different vertices and build a fault-tolerant topology. If necessary, it is possible to generate alternative topologies that work at other frequencies. In this way, the graph has several dimensions and the geographical binding of the switch to the router, which allows you to effectively monitor the use of communication channels and reconstruct traffic according to needs. The block diagram of the algorithm for generating the topology of a software-defined network using a random geometric graph of intersections is shown in Figure 4.

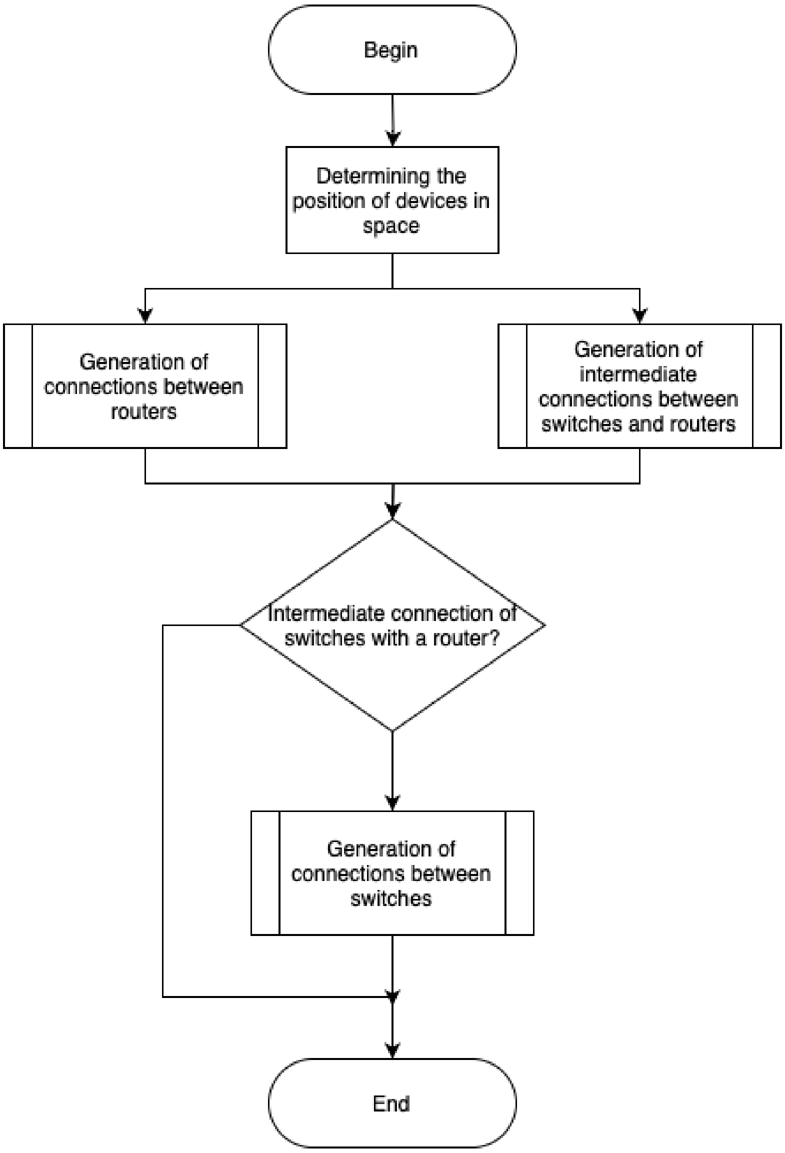


Fig. 4 Diagram of the SDN network topology construction algorithm using a random geometric graph of intersections

The NetworkX 3.3 library and Neo4j 5.20 graph database were used to generate the topology. A module was developed that created a graph object based on the entered number of Southbound and Northbound devices and radius. The module also communicated with the Neo4j database in order to save and use the SDN network topology graph in further research.

4.2. Investigating of communication channel congestion

When using networks of the 802.11 standard, quality indicators of the network, such as data transfer speed, delay, packet loss, depend on the load of the communication channel. When investigating the impact of the communication channel load, the Asus AX-56 WiFi adapter on the Realtek RTL8832AU chipset with 802.11ax and MIMO 2x2 support was used; network WiFi card Asus PCE-AC88 with support for 802.11ac and MIMO 4x4; firewall Cisco Adaptive Security Appliances (ASA) 5506-X Internetworking Operating System (IOS) 7.18(1)152); WiFi access point with a Cisco Catalyst 9115 controller with support for 802.11ax, MIMO 4x4, 160 Mhz, IOS 17.09.04a. With the help of the inSSIDer utility, an analysis of the use of radio air was carried out and a list of access points with supported 802.11 protocols, the used WiFi channel and the level of the dBm signal was created.

The network was configured and data transfer rate and latency measurements were made using the iperf utility. The measurements were carried out at different load levels of communication channels and by configuring the network for different 802.11 protocol standards with different MIMO modes.

5. Results of investigating the method of reconfiguration wireless SDN networks

5.1. Analysis of the relevance of methods of using random graphs in SDN networks

The scientific value and relevance of the research lies in the use of random geometric intersection graphs for topology construction in software-configured wireless networks. In the course of the study, the key parameters important in this type of networks were identified: The clustering coefficient, the presence of isolated elements of the graph, proximity to control elements. In the first stage, the positions of Northbound and Southbound switches were generated. Visualization of their mutual location can be seen in Figure 5.

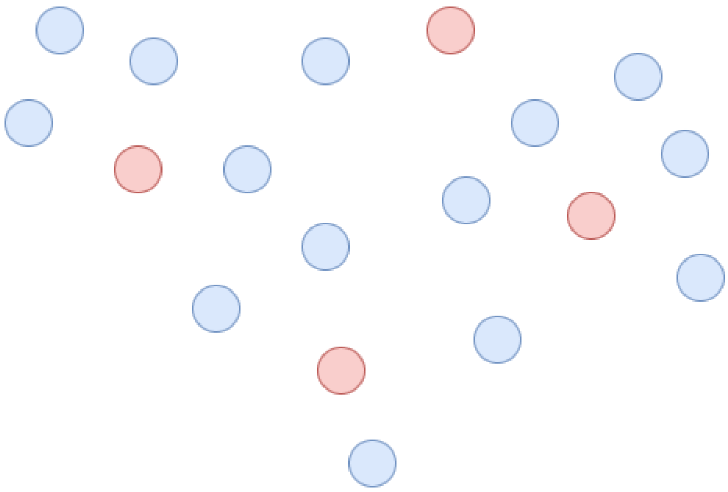


Fig. 5 Result of placement of devices in space

At the second stage (Fig. 6), intermediate connections between Northbound and Southbound devices are formed. In the formation of these connections, a large role is played by the radius, which affects the appearance of connections between vertices. Using a large radius will result in excess connections and increase the average degree of the vertex. Decreasing the value of this parameter will result in a greater number of isolated vertices.

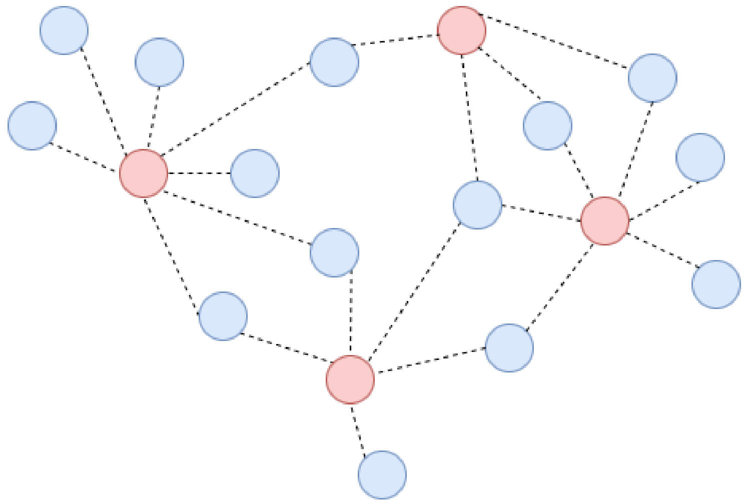


Fig. 6 Result connections between Northbound and Southbound devices

At the third stage (Fig. 7), permanent connections are formed between Southbound devices, provided that both Southbound devices had an intermediate connection with the same Northbound device. This allows you to achieve local clustering by increasing the number of connections between devices that are at a distance equal to the radius value.

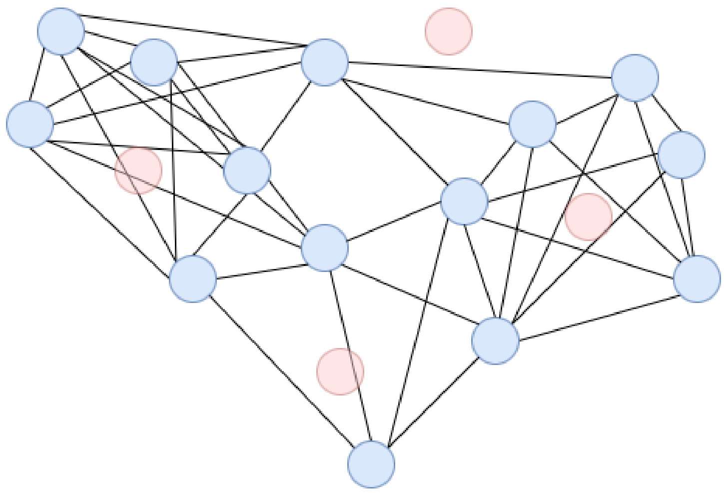
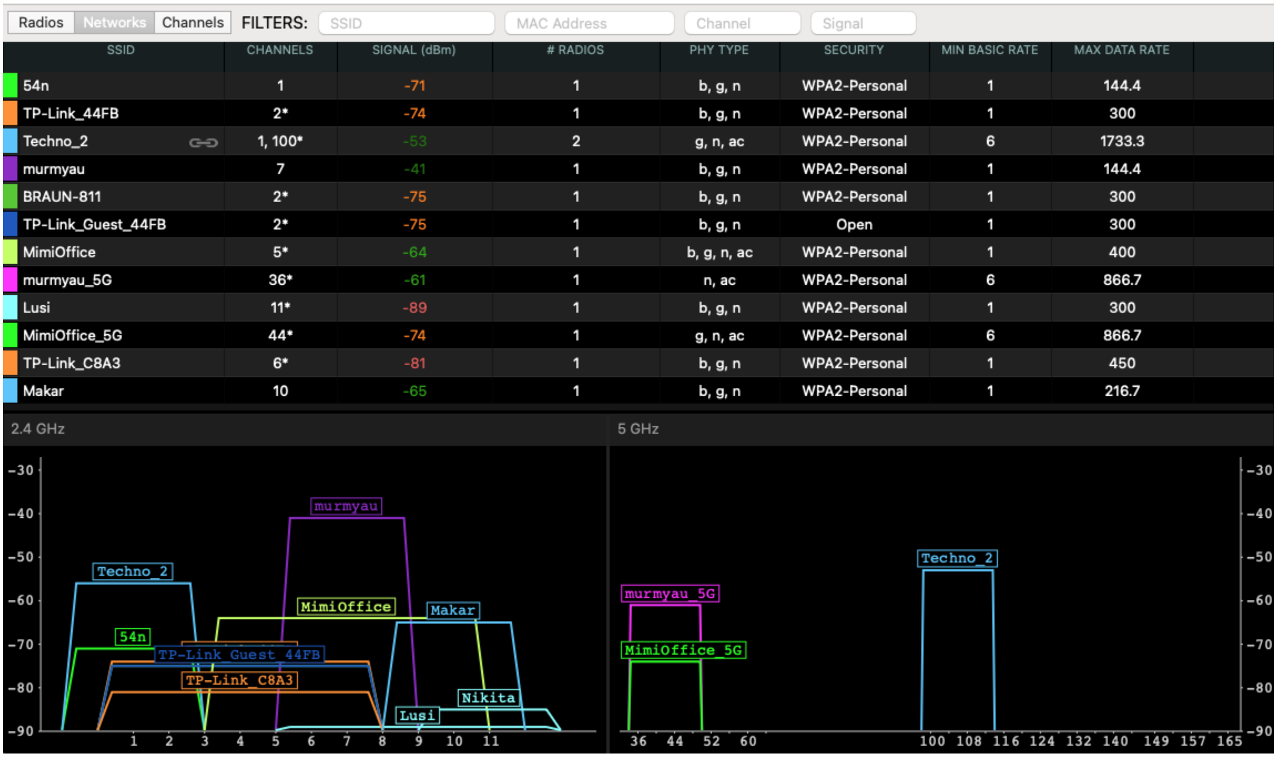


Fig. 7 Result connections between Southbound devices

Thus, it was established that to increase the fault tolerance of a wireless software-configurable network, it is necessary to have a greater number of short links, given the proximity to the control device. In this way, the network capacity will be greater, since the signal level drops and the quality characteristics degrade as the distance increases. Therefore, the use of a random geometric graph of intersections is the most optimal choice considering the architecture of SDN networks and the general approach to building such networks.It is worth mentioning that this topology generation method can be used not only in wireless SDN networks. Thus, reconfiguring links between devices can take longer and be more difficult to implement.

5.2. Study of the impact of communication channel congestion in wireless networks

In the course of the study of the impact of congestion, a report on the use of IEEE 802.11 wireless network channels was obtained. The report can be seen in Figure 8.



SSID	CHANNELS	SIGNAL (dBm)	# RADIOS	PHY TYPE	SECURITY	MIN BASIC RATE	MAX DATA RATE
54n	1	-71	1	b, g, n	WPA2-Personal	1	144.4
TP-Link_44FB	2*	-74	1	b, g, n	WPA2-Personal	1	300
Techno_2	1, 100*	-53	2	g, n, ac	WPA2-Personal	6	1733.3
murmyau	7	-41	1	b, g, n	WPA2-Personal	1	144.4
BRAUN-811	2*	-75	1	b, g, n	WPA2-Personal	1	300
TP-Link_Guest_44FB	2*	-75	1	b, g, n	Open	1	300
MimiOffice	5*	-64	1	b, g, n, ac	WPA2-Personal	1	400
murmyau_5G	36*	-61	1	n, ac	WPA2-Personal	6	866.7
Lusi	11*	-89	1	b, g, n	WPA2-Personal	1	300
MimiOffice_5G	44*	-74	1	g, n, ac	WPA2-Personal	6	866.7
TP-Link_C8A3	6*	-81	1	b, g, n	WPA2-Personal	1	450
Makar	10	-65	1	b, g, n	WPA2-Personal	1	216.7

Fig. 8 Report of the inSSIDer utility

It was established that the highest load of channels occurs in the frequencies of the 2.4 GHz range, namely, channels 1, 4 and 7 have a load of 50%. This is due to the greater prevalence of the IEEE 802.11n protocol. Channels in the 5 GHz band are less loaded, and upper-level channels (above 100) have no load at all, as they are more common in the business segment.

In the study of the impact of wireless communication channel congestion, attention was paid to the MIMO parameter, which significantly increases the speed. The results of the download speed study can be seen in Figure 9. As the percentage of channel utilization increases, the transmission speed in it drops from 570 to 183 Mbit/c in 802.11ac 4x4 MIMO mode.

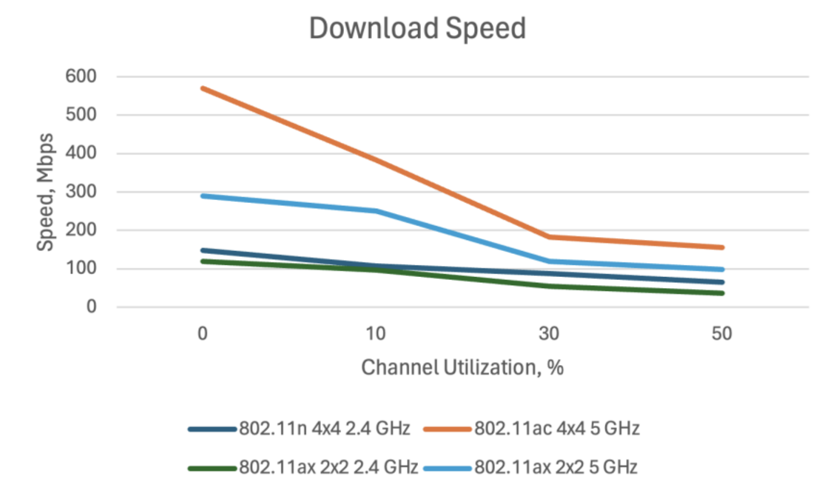


Fig. 9 Dependence of the download speed on the load of the data transmission channel

When using a newer protocol, however, with a lower MIMO parameter, the speed also decreases by almost 2 times. However, it should be mentioned that the use of an increased number of transmitters and receivers reduces the influence of the channel load on the speed. Despite the increased dimension of QAM in the 802.11ax protocol, the speed compared to 802.11ac is 1.5-2 times lower, depending on the channel load.

Similar measurements of the unloading speed are presented in Figure 10.

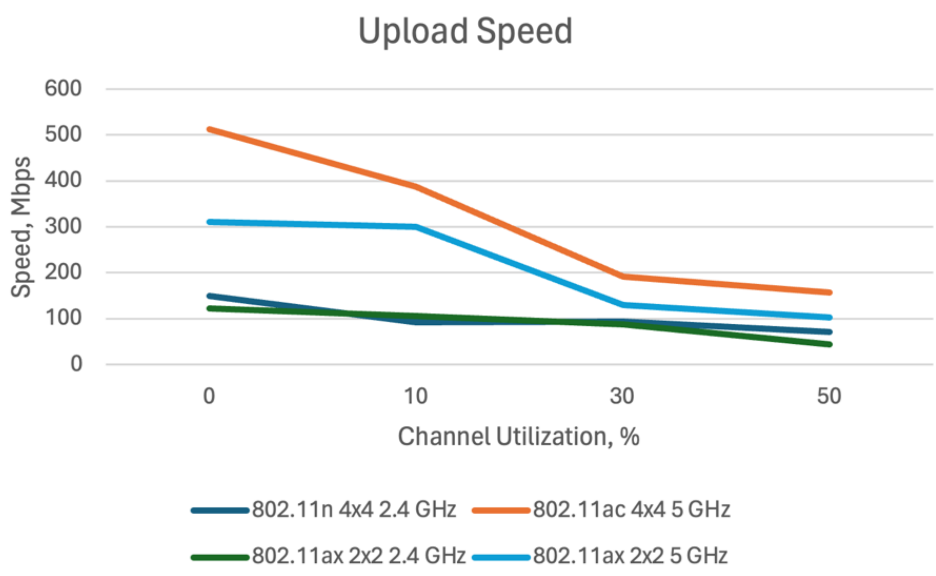


Fig. 10 Dependence of the download speed on the load of the data transmission channel

Figure 11 represents the graph of the dependence of the delay on the channel load. The IEEE 802.11n protocol operating in the 2.4 GHz range is the most vulnerable to channel congestion. When the channel is loaded at 50%, the delay reaches 15 ms, which does not meet the requirements for video conferences and other types of communication.

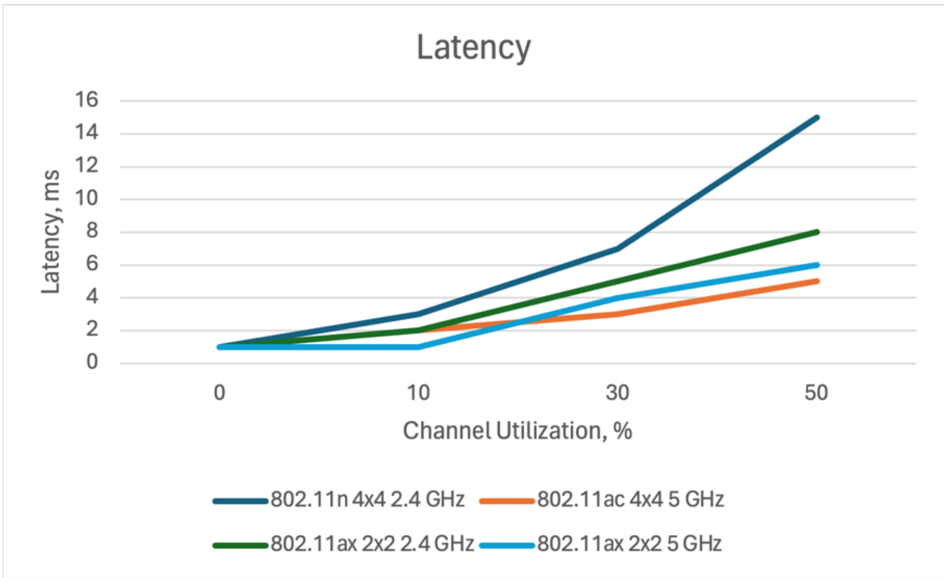


Fig. 11 Dependence of the delay on the load of the data transmission channel

Alternatively, when using 802.11ac or 802.11ax and channels in the 5 GHz range, the delay increases to 5-6 ms, which is an acceptable value for the transmission of audio and video communications. It should also be noted that the influence of the MIMO parameter on the delay is not significant, in contrast to the data transfer rate. When using the 4x4 mode, the difference in delay is 1ms. These results show that the 5 GHz band is better for streaming audio, video and remote communication.

6. Discussion of the results of the study of reconfiguration methods of wireless SDN networks

The use of random geometric intersection graphs makes it possible to increase the clustering coefficient without creating redundant connections by taking into algorithm the position of Southbound devices relative to Northbound devices. The developed topology generation method allows generating alternative topologies for switching in case of increased traffic on the communication channels of the selected band. This makes it possible to increase the fault tolerance of the network and the speed of topology reconfiguration.

The obtained results of the study show the influence of the channel load in the WiFi network. When the load on the communication channel increases, the speed of information transmission decreases, and the delay increases. At the same time, older WiFi protocols 802.11 b, g, n have greater losses in the quality of data transmission than newer protocols such as 802.11 ac, ax. This is due to the use of Beamforming technologies - signal amplification technology due to the interference of waves from different transmitters, as well as modulation by the method of quadratic amplitudes of a higher rate: 64 bits in 802.11n and 256 bits in 802.11 ac. However, as a result of research, it was found that when comparing the protocols 802.11 ac in MIMO 4x4 mode and 802.11 ax in MIMO 2x2 mode, the data transfer rate is higher and has a lower delay. Therefore, the effect of modulation and multiplexing with orthogonal frequency division channels, which was introduced in the 802.11 ax protocol, has a smaller effect than the number of independent receivers and transmitters.

In further research, it is planned to use DPI technology to distribute the load between different communication channels and evenly use all Southbound devices in the network. It is planned to develop the dynamic switching of the width of the IEEE 802.11 data transmission channel depending on the load and the use of neighboring communication channels by other networks to improve the characteristics of data transmission in a wireless SDN network. Attention should also be paid to researching the dependence of data transmission parameters on the distance of Southbound devices.

7. Conclusion

1. A comparative analysis of the use of random geometric intersection graphs in comparison to Erdős–Rényi graphs and a geometric graph in SDN networks theoretically substantiated the advantages of using a random geometric intersection graph in the topology generation method of a fault-tolerant SDN network. Its ability to build connections between Southbound devices based on the distance from Northbound devices allows to increase the fault tolerance of the network and to create alternative routes and topologies in case of an increase in the use of data transmission channels.

2. A number of experiments were conducted to check the dependence of speed and delay on the load of the data transmission channel in the IEEE 802.11 wireless network. Different versions of the 802.11 protocol were investigated in different frequency bands and with different MIMO parameters. It was found that MIMO 3x3 or higher should be used to reduce the impact of channel congestion on speed. This provides an average speed increase of 18% compared to MIMO 2x2. However, one should take into account the influence of the distance between the devices, which was unchanged in this series of experiments.

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МЕТОД ДИНАМІЧНОЇ РЕКОНФІГУРАЦІЇ ПРОГРАМНО-КОНФІГУРОВАНИХ МЕРЕЖ

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В статті представлений метод динамічної реконфігурації бездротової програмно-конфігурованої мережі з використання випадкових геометричних графів перетину.

Розмірність мереж і глобалізація бізнесу зростають, тому потреби в ефективному управлінні мережею та підвищенні швидкості та надійності передачі даних стають дедалі гострішими. Основним завданням ефективної роботи пристроїв є підвищення відмовостійкості мережі та покращення її швидкісних характеристик. Поширення віддаленої роботи вимагає адаптації компонентів інфраструктури на підприємствах для безпечної та швидкої переналаштування відповідно до потреб бізнесу. Тому розробка нових методів реконфігурації топології комп'ютерних мереж і поліпшення характеристик передачі даних є одними з найбільш актуальних проблем галузі.

Метою даного дослідження є розробка методу реконфігурації програмно визначених бездротових мереж для підвищення відмовостійкості мережі та покращення характеристик

передачі даних. Це дозволить продовжити передачу даних і запобігти втраті інформації при втраті певних каналів зв'язку або їх перевантаженні іншими мережами чи засобами впливу.

Об'єктом дослідження є процес генерації топології програмно-конфігурованої мережі за допомогою теорії графів, а саме – випадкових геометричних графів перетину. Також об'єктом дослідження є вплив завантаженності бездротового каналу зв'язку на якісні характеристики каналів передачі даних.

Для досягнення поставленої мети були поставлені наступні задачі:

– розробити метод генерації топології мережі SDN за допомогою графа випадкового геометричного перетину.

– визначити вплив показника завантаженності каналу бездротового зв'язку на швидкість передачі даних. Провести дослідження з різними типами налаштувань точок доступу в протоколах IEEE 802.11 n, ac, ax з різними режимами multi input multi output (MIMO).

Порівняльний аналіз використання графів випадкових геометричних перетинів у порівнянні з графами Ердеша–Реньї та геометричним графом у мережах SDN теоретично обґрунтував переваги використання графа випадкових геометричних перетинів у методі генерації топології відмовостійкої мережі SDN. Також було досліджено вплив завантаженності каналу зв'язку в бездротових мережах. Встановлено, що параметр MIMO впливає на характеристики мережі більше ніж QAM та OFDMA.

Результати практичних досліджень підтверджують правильність обраних методів для реконфігурації бездротових SDN мереж.

Ключові слова: випадковий граф, генерація топології, SDN.