Evaluation Method for SDN Network Effectiveness in Next Generation Cellular Networks

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***Abstract*:** 5G mobile technology will become the new standard in the mobile communication market. New networks will focus on significantly improving service quality. The basis for their construction will employ Software Defined Networking (SDN) networks. Therefore, the advantages and disadvantages of two SDN implementing methods are analyzed. A mathematical method is used to assess their complex effectiveness, which considers Quality of Service requirements for implementing service through special weights for scalability, performance, and packet delay. Simulations of Overlay networks are modeled by using software-based switches to verify the adequacy of the proposed method. The results show that the use of SDN is more efficient by using IP networks for large volumes of traffic and with a large amount of network equipment. Different approaches to building SDN management level architecture are compared. Based on our studies and modeling, we suggest the use of distributed controller architecture because of its higher level of reliability.

***Keywords*:** SDN networks, architecture, management level structure, 5G mobile, quality of service, openFlow.

1. Introduction

Cellular systems that combine the broad capabilities of conventional radio and telephone communications have become a vital basis for the development of business activity, improving state management systems as well as human communication [1]. As new technology develops, newer and more improved computing devices become available, providing users with more options and necessitating the presence of high-speed wireless Internet connections and driving their demand among users. In response to this increased demand, mobile service providers are introducing new technologies to their networks that are able to provide users with the necessary bandwidth and throughput to ensure high service quality.

Technology continues its development towards higher productivity, presenting a greater number of opportunities. To solve tasks that were impossible to solve using 3G and 4G, new technologies are appearing to supplement the existing range of radio access technologies.5G networks are a new generation of radio systems and network architecture that presents maximum broadband with ultra-reliable, low latency connectivity and a robust network for users and the Internet of things [2,14].

5G will be much more than just a new radio technology. It will combine existing radio access technology with new bands optimized for specific frequencies, deployment of networks, and use case scenarios. 5G will also use novel network architecture based on Network Function Virtualization (NFV) and Software Defined Networking (SDN) [3, 4].

SDN technology is perspective in the field of telecommunications. If we compare it with the traditional networking model, which is still relevant today, including Ukraine, SDN model has several advantages. Developers identify the following: improving the efficiency of network equipment by 25–30%; network operating costs decrease up to 30%; it enables users to create new software services and quickly upload them to the network equipment.

SDN concept involves separation of traffic and control plane [5]. In SDN networks, all hardware configurations (control plane) is reassigned to a single central controller. Thus, SDN switches are simple devices, as their only function is switching and data transmission (traffic plane). This improves the efficiency of network operations and increases processing speed compared to traditional networking, especially for large volumes of traffic, as traditional networks require each device to perform routing independently.

Implementation of the SDN concept in practice will provide independent equipment manufacturers control over an entire network from a single location, which greatly simplifies its operation. The simplification of network configuration is equally important, as administrators do not have to enter hundreds of lines of code for individual switches or routers, and network parameters can be quickly changed in real time. Accordingly, the time required to introduce new applications and services will greatly reduce.

To implement SDN networks, two basic methods are used [6]:

1. Implementation of SDN based on the specific switch (OpenFlow protocol).
2. Implementation of SDN Based on the Virtual Switch by Overlay Technology.

Software-configured networks allow the use of extended functionality for computer network management. For example, it allows centralized management of all network resources (such as communication channels and network equipment), the ability to use software applications for the automatic management of network equipment configuration, the provision of additional network security, automatic network reconfiguration in case of equipment failure or link breakage, and the provision of Quality of Service (QoS) options such as traffic prioritization. In addition, SDN networking simplifies network equipment management through standardization of the controller interaction protocol and the physical infrastructure. In this case, equipment guided by the controller can perform functions not native to modern switches (e.g., firewall function). SDN networking also optimizes routing for data streams and provides tools for lightweight networks virtualization. Therefore, SDN networks can be used in the architecture of present and future cellular networks.

2. Using the SDN Concept in Cellular Networks

SND and SDR architecture involves replacing the varied equipment types of a network (BSC, RNC, MSC, MGW, SGSN, GGSN, MME, S-GW, P-GW, etc.) with a common hardware platform on which all their functions are virtualized. Rather than employing a wide variety of equipment, a single powerful hypervisor is used to run virtual machines, each of which performs a hardware function. Fig. 1 shows network architecture using SDR/SDN. This architecture allows the creation of modern mobile networks which can easily switch between standards (i.e., GSM, UMTS, and LTE) and provide new services more quickly. In addition, software-configured network can fundamentally change optical transport networks, as SDN will apply centralized network control, ensuring its programmability and automation as well as providing different services for different. QoS. Therefore, Open Networking Foundation (ONF) conducts development of open transport switches (OTS), which act as intermediaries between the controller and the optical switch.

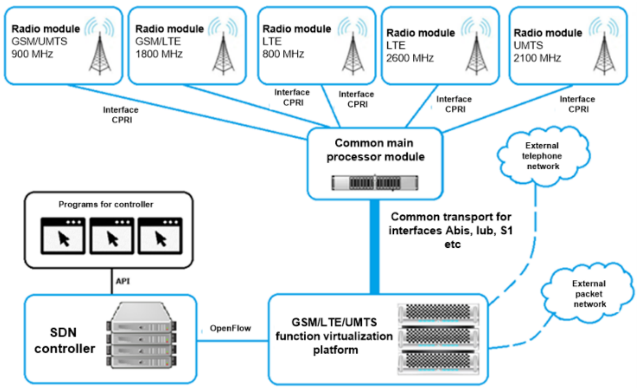

Figure 1. Architecture of mobile network using SDN and SDR

An OTS is a server with a virtual software switch installed on it. Its internal structure is shown in Fig. 2. An OTS communicates with its controller via the OpenFlow protocol. A specific command syntax is used for a specific switch to interact with the optical switch. In an optical network, an OTS that is connected to a switch receives information about the parameters of the switch and transmits that information to the controller. Thus, the controller receives a complete view of network resources, such as the number of channels, bandwidth, QoS parameters, etc.

OTS internal modules transmit hardware parameters to the controller, notify the controller about the state changes of the channel, and monitor performance. Optical switches of different manufacturers require different OTS modifications, although most of the code is the same, and some modules differ because they interact directly with the physical switch interfaces.

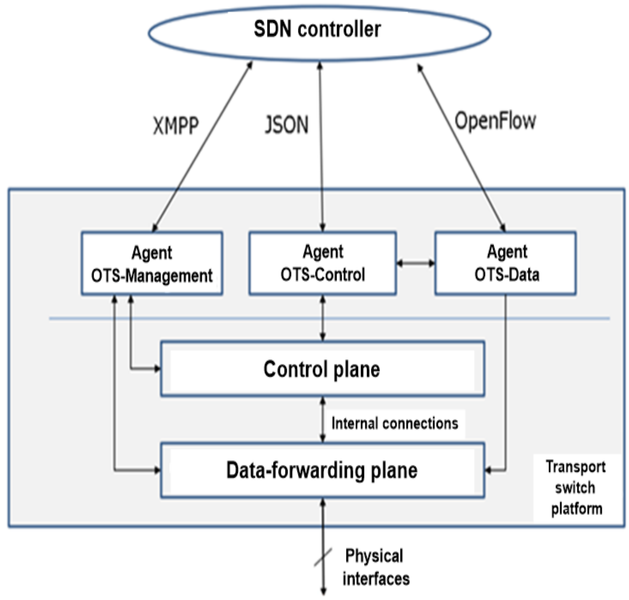

Figure 2. The logic of Open Transport Switch

Control system by using OTS can operate in two modes: explicit and implicit, which are discussed in detail in [6].

To manage network nodes that do not have a connected OTS, a software application of the controller can be used. For example, developed by Adva [7], for converting OpenFlow controller commands to SNMP and vice versa. However, in this case, management capabilities are limited by the possibilities of the SNMP protocol.

Also, SDN networking can be used to discharge the radio interface of cellular networks (Fig. 3).

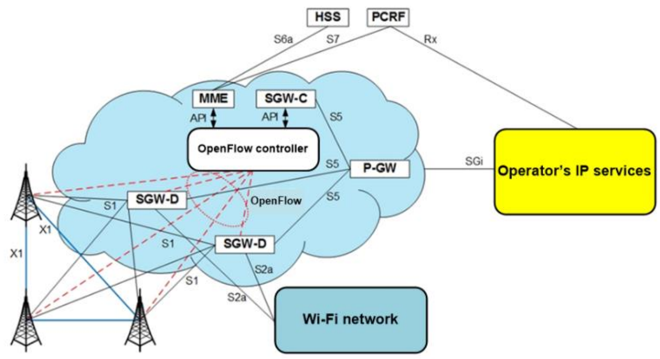

Figure 3. The use of an SDN controller for discharging radio interface

Thus, the concept of SDN is nearly unchanged in many different applications of next generation networks. Therefore, it is necessary to develop a method for efficiency estimation of such networks and assess it in terms of the existing requirements for next generation mobile networks.

Designing a network is a challenging task for every operator. The first step is to understand common networking requirements. After identifying these requirements, we can select key network characteristics that meet these requirements. Networking devices must reflect the goals, characteristics, and policies of the service provider in which they operate. Two primary goals drive networking design and implementation: Application availability and Cost of ownership. A well-designed network can help balance these objectives. When properly implemented, the network infrastructure can optimize application availability and allow the cost-effective use of existing network resources.Therefore, when designing or optimizing the network, we have to know the main requirements for the new applications which we want to implement.

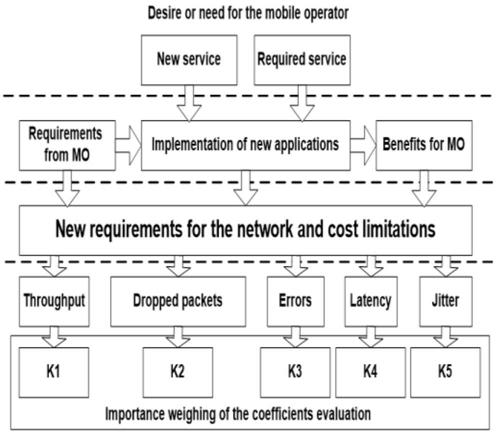

Figure 4. New application implementation process

As shown in Fig. 4, when implementing a new service, the mobile provider has to check the main characteristics of the network for compliance with the minimum threshold for each application to be implemented. Some characteristics will be more valuable, as some are not critical for a given application. Thus, we will use weights K1 – K5on future calculations for total efficiency.

Table 1. Value delay and transmission rate for various services

Type of service	Speed of receiving data			
	0.3 Mbs	1 Mbs	2 Mbs	6 Mbs
Open Website (1.2 MB)	32 s	10 s	5 s	2 s
Download email with attachments (5 MB)	133 s (2 min)	40 s	20 s	7 s
Download the map in Google Maps (≈3.5 MB)	91 s	27 s	14 s	5 s
Download Flash game (3 MB)	80 s	24 s	12 s	4 s
Audio streaming (10 MB)	267 s (4 min)	80 s	40 s	13 s
HD – Full HD Video streaming from YouTube (40 MB)	1067 s (18 min)	320 s (5 min)	160 s (3 min)	53 s
Download the file from the server FTP (100 MB)	2667 s (44 min)	800 s (13 min)	400s (7 min)	133 s (2 min)

The most popular applications among users were tested. For example, 3 separate minutes of calls were allocated for each application, and the amount of data used for each call was recorded. Then the average of these three amounts was calculated for the final result. Each side was given 30 s to speak, simulating a 1-min conversation.

Test results are summarized in the table 1. We can conclude that high speed bandwidth and low packets latency are necessary for the satisfactory use of advanced applications and services in networks.

3. Evaluation of SDN Network Efficiency

To ensure the effective functioning of SDN networks, characteristics such as performance, latency, and scalability must first be assessed. These characteristics depend on the number of managed switches, their connectivity with the controller, the intensity of received requests, and the time query processing of the controller. Thus, the efficiency of SDN networks depends on the controller's capability to adapt to the increasing intensity of incoming requests from switches and to ensure the quality of service by increasing the scale of the network [11]. Thus, network scalability evaluation, based on the concept of SDN, delay, and productivity, is an important task in the design of new implementations and in the expansion of existing network architecture [13].The main goal of this work is the development of an efficiency evaluation method for SDN networks, which will allow the calculation of the main characteristics of SDN (latency, performance, and scalability) for each type of network in a variety of cases.

Determining the efficiency of entire SDN networks, or parts thereof, for a particular application will be kept to the definition of complex criteria using the analytic hierarchy process for each mobile operator. First, as shown in Fig. 5, a definition of priorities will be conducted for different criteria. Fig. 5 shows the hierarchy in which the default priorities of elements are considered equal, that all four criteria are of equal importance from the standpoint of goal, and priorities of all alternatives are equal in all criteria. In other words, alternatives are indistinguishable in this example. Thus, the number of elements with priority at any level, is one.

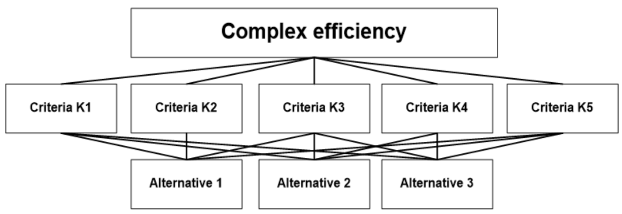

Figure 5. The hierarchical AHP structure with priorities

Global alternatives priorities regarding the aim are computed by multiplying the local priority of each alternative on each criterion priority and summation for all criteria.

Acceptation of priorities solutions can be either based on objective data (including optimization methods and probabilistic and statistic models) or based on the views of specialist (experts). In tasks of feasibility analysis always uses a variety of expert estimates methods.

To assess the complex effectiveness, the use of a simpler model is proposed (Fig. 6).

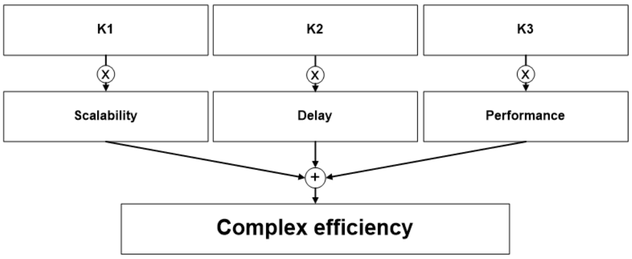

Figure 6. The complex efficiency estimation model for SDN networks

In this model (Fig. 6), complex efficiency is defined as the weighted sum of scalability, network delays, and performance. Thus, further development of mathematical tools and the modeling of SDN networks to determine complex efficiency will be conducted where it is necessary.

To compare the quality of data transmission, the following parameters are used: bandwidth, packet transmission delay, jitter, and packet loss rate [12]. Delay is the most important indicator of quality, so it is useful to compare the average packet delay in SDN/OpenFlow, SDN/Overlay, and IP networks.

To evaluate the average packet delay in Overlay SDN networks, we make use of Mininet, which is an environment for modeling SDN networks, and MiniEdit, a graphic editor for Mininet. Mininet provides emulation of SDN network operation, and allows the creation of realistic virtual networks.

We construct a simple network topology in MiniEdit that consists of two hosts (h1 and h2), four software Open vSwitch switches(s1, s2, s3, and s4), and a network controller (c0). The final topology is shown in Figure 7.

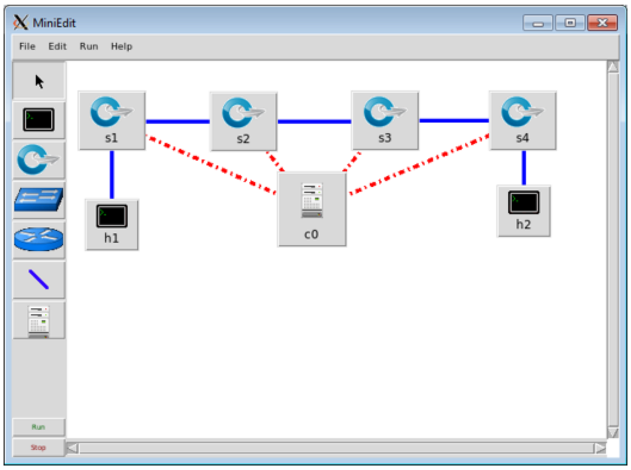

Figure 7. Network topology in MiniEdit

To assess packet transmission time in such networks, the *ping* command was used to send packets between h1 and h2.On the basis of the obtained data, mathematical modeling was carried out in Mathcad. Next, the input data for modeling is defined.

Assume a time of transmission channel as 0.002 ms (as set in the environment MiniEdit):

t_{link}=0.002 ms – delay time in the channel.

As noted above, the processing time of the controller is 25 ms:

t_{ctrl}= 25 ms – processing time of controller.

The average time of network transmission with 4 switches, was determined to be 0.115 ms. To determine the average processing time of packet by a single switch, the below calculation is performed, considering that there are 5 channels between hosts:

$t_{OVS}= (0.115 - 5 \cdot t_{link})/4$ – packet processing time in Open vSwitch.

We let OpenFlow switches assume the packet processing speed of the Open vSwitch. The processing time of packets via Open vSwitch includes also the transmission from physical to virtual switch and vice versa. Thus, to determine OpenFlow processing time, we subtract two delays in the communication channel:

$t_{OFS} = t_{OVS} - 2 \cdot t_{link} = 0.022$ ms – packet processing time in an OpenFlow switch.

To determine the processing time of packets via traditional switch, we take characteristics close to those of the switches used in Mininet. An example of such a switch is the DES-1005A, which processes 14,880 packets per second. The processing time of packets via such a switch is calculated as below:

$t_{switch} = 1000/1488 = 0.067$ ms – packet processing time in IP switch.

In this topology, 4 switches and 5 channels are used between hosts:

$n = 4$ –number of switches;

$m = n+1$ – number of channels.

The packet delivery time of each type of network is calculated next. IP, SDN/OpenFlow, SDN/Overlay network topologies are shown in Fig. 8.

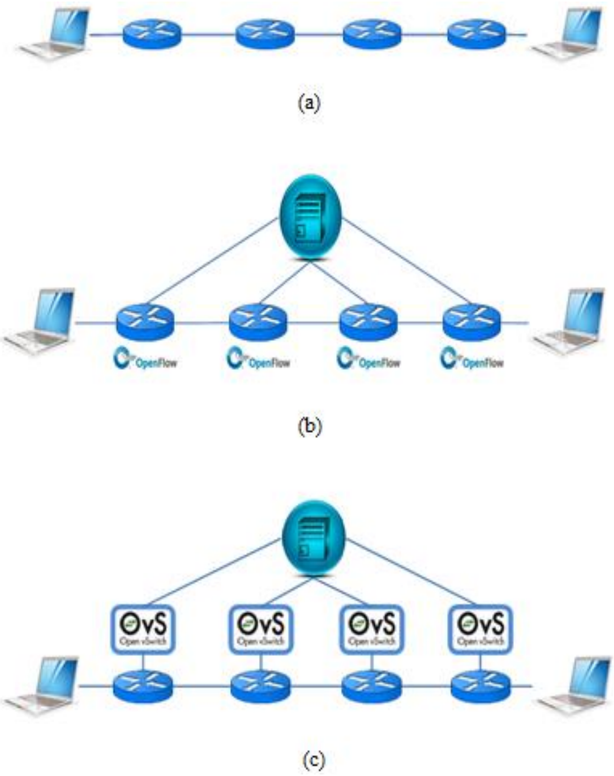

Figure 8. Researched topology networks:
a – simplified IP network topology; b – simplified SDN/OpenFlow network topology; c – simplified SDN/Overlay network topology

In IP networks, general packet delivery time is the amount of delay per channel and processing time in each switch:

$$t_{IP}(p) = m \cdot t_{link} + n \cdot p \cdot t_{switch}$$ – for IP-switches.

In SDN/OpenFlow networks, the total time of packet delivery is calculated as the sum of delay per channel and processing time in each switch including the delivery time of information about the first packet to the controller and vice versa, as well as the deciding time of controller:

$$t_{SDN\_OFS}(p) = m \cdot t_{link} + n \cdot p \cdot t_{OFS} + 2 \cdot t_{link} + t_{ctrl}$$ – for OpenFlow switches.

In SDN/Overlay-networks, the total delivery time of packets is calculated identically to SDN/OpenFlow networks, excepting that OpenFlow switch processing time uses the software Open vSwitch processing time, which accounts for packet delivery time from the physical to the virtual switch and vice versa:

$$t_{SDN\_OVS}(p) = m \cdot t_{link} + n \cdot p \cdot t_{OVS} + 2 \cdot t_{link} + t_{ctrl}$$ – for Open vSwitch switches

Total packet delivery time should be divided by the number of packets to calculate the average packet delay:

$$t_{average\_IP}(p) = (m \cdot t_{link} + n \cdot p \cdot t_{switch})/p$$ – for IP-switches;

$$t_{average\_SDN\_OFS}(p) = (m \cdot t_{link} + n \cdot p \cdot t_{OFS} + 2 \cdot t_{link} + t_{ctrl})/p$$ – for OpenFlow switches;

$$t_{average\_SDN\_OVS}(p) = (m \cdot t_{link} + n \cdot p \cdot t_{OVS} + 2 \cdot t_{link} + t_{ctrl})/p$$ – for Open vSwitch switches.

The next step is to construct dependency graphs of the total packet delivery time and average delay against the number of packets in the data stream. Graphs of dependence for the three types of networks are shown in Fig. 9 and 10. Graphs are built for packet quantities from 1 to 1000. The red solid line corresponds to the IP network, the green dashed line corresponds to the SDN/Overlay network, and the blue dotted line corresponds to the SDN/OpenFlow network.

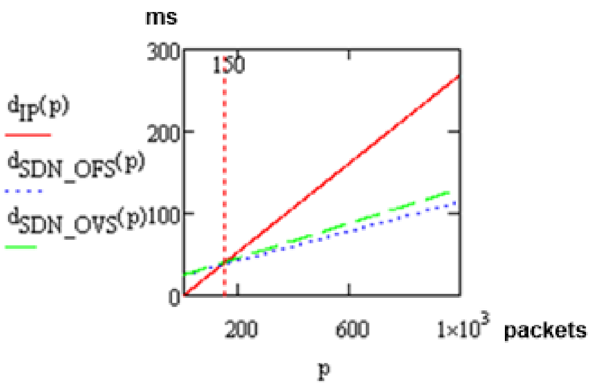

Figure 9. Total time of data transmission against the number of packets (when n = 4)

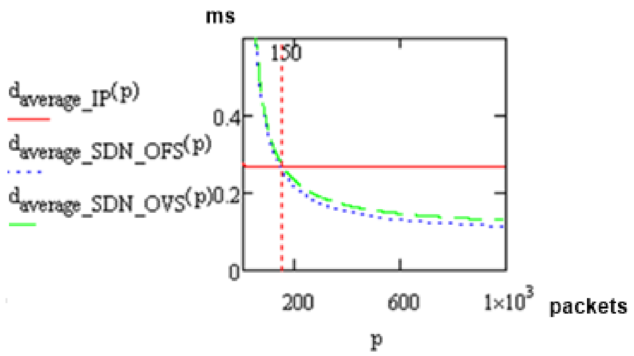

Figure 10. The average packet delay against the number of packets (when n = 4)

From the dependency graphs, we can conclude that the average delay in SDN networks decreases as the number of packets in the stream increases. The number of packets in the flow does not affect the average delay in traditional networks. Thus, the hypothesis is confirmed that SDN is efficient when used in networks with a large volume of traffic, so networks with OpenFlow switches are more efficient than a network built on Overlay.

We then calculate how delay changes in each network depending on the amount of networking equipment (switches). For purity calculations, we will take the number of packets when the average delay is about the same for all networks. As seen from the graphs, the lines intersect roughly at the mark of 150 packets, the number of packets is defined as p = 150.

Total time of data transmission depending on the number of switches expressed by features:

$$t_{IP}(n) = (n+1) \cdot t_{link} + n \cdot p \cdot t_{switch}$$ – for IP switches;

$$t_{SDN\_OFS}(n) = (n+1) \cdot t_{link} + n \cdot p \cdot t_{OFS} + 2 \cdot t_{link} + t_{ctrl}$$ – for OpenFlow switches;

$$t_{SDN\_OVS}(n) = (n+1) \cdot t_{link} + n \cdot p \cdot t_{OVS} + 2 \cdot t_{link} + t_{ctrl}$$ – for Open vSwitch switches.

The average packet delay depending on the number of switches expressed by features:

$$t_{average\_IP}(n) = ((n+1) \cdot t_{link} + n \cdot p \cdot t_{switch})/p$$ – for IP-switches;

$$t_{average\_SDN\_OFS}(n) = ((n+1) \cdot t_{link} + n \cdot p \cdot t_{OFS} + 2 \cdot t_{link} + t_{ctrl})/p$$ – for OpenFlow switches;

$$t_{average\_SDN\_OVS}(n) = ((n+1) \cdot t_{link} + n \cdot p \cdot t_{OVS} + 2 \cdot t_{link} + t_{ctrl})/p$$ – for Open vSwitch switches.

We construct dependency graphs of the total packet delivery time and the average delay against the number of switches in the network. The dependency graphs for the three types of networks are shown in Fig. 11 and 12. Graphs are built for quantities of switches from 1 to 16.

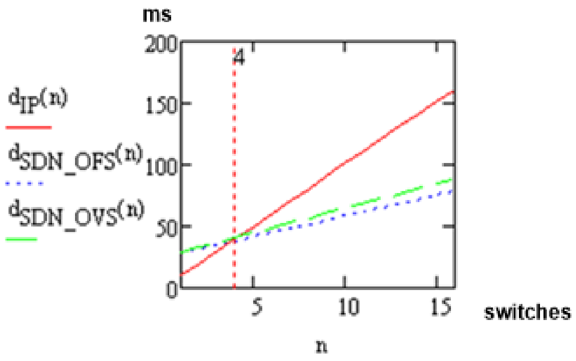

Figure 11. Total time of data transmission against the quantity of switches (p = 150)

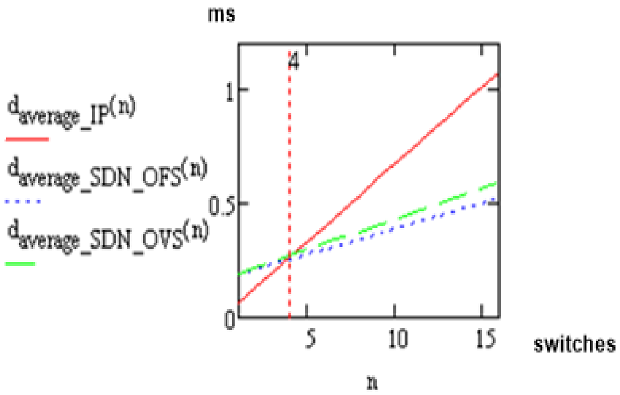

Figure 12. The average packet delay against the quantity of switches (p = 150)

From the above graphs, we conclude that average delay correlates less strongly with the quantity of switches in an SDN network relative to a traditional network. At 16 switches, the gain in delay is more than in 2 times. Therefore, SDN is efficient for networks with a large amount of networking equipment. Additionally, networks with OpenFlow switches are more efficient than networks built on Overlay.

4. Network Performance and Scalability

At the management level of SDN performance F(N) can be defined as follows [9]:

$$F(N) = \varphi(N) \cdot \frac{T(N)}{C(N)}$$

where N – the number of network nodes
φ(N) – the capacity of management level in network requests processing
T(N) – the average response time of each request
C(N) – the cost of management level deployment

Scalability for SDN management level, when the size of the network varies from N_2 to N_1, is defined as [9]:

$$\psi(N_2, N_1) = \frac{F(N_2)}{F(N_1)}$$

where $F(N_2)$ – management level performance in processing requests from N_2 network elements
$F(N_1)$ – management level performance in processing requests from N_1 network elements
We carry out an evaluation of SDN network scalability appropriate for the three main architectures. Depending on controllers' connectivity, management level structure can be roughly divided into three types: centralized, decentralized, and hierarchical.

- The centralized management level structure has only one controller. The controller has information about all network states and processes all initial flow requests. This is in contrast to decentralized and hierarchical structures, which have several controllers.
- In the decentralized structure, controllers perform equal functions and have equal relationships with each other. There are two ways to build a decentralized structure. According to the first method, each controller has information about the global network topology. When using the second method, each controller has information only about the topology of its local network, and each of the neighboring LANs abstracts as a logical unit.
- In the hierarchical structure, there is a distribution of functional responsibilities between the controllers. In the hierarchical structure, controllers and switches are arranged in a tree, and controllers are divided into different levels. There are two different types of controllers in the architecture: local controllers and global controllers. Local controllers are not subordinate to other controllers, and they manage all the switches in the subnet, while the root controller controls only its local controllers.

Scalability of the management level depends on the type of structure that will be used. Different types of structures have dependencies for the average response time upon request as shown in Table 2 [10].

Table 2. Average response time upon request in SDN networking

SDN network structure	Average response time upon request
Centralized structure	$E(T_C(N)) = \frac{1}{\mu_C - \lambda_C}$
Decentralized structure	$E(T_{d,l}) = \frac{L_{D,l}.m_D}{N.(N-1).\lambda} = \frac{1 + \frac{N.(m_D - 1|)}{(N-1).m_D}.d_D}{\mu_{D,l} - \lambda_{D,l}}$
Hierarchical structure	$E(T_H) = \frac{\frac{N - \frac{N}{m_H}}{N-1}}{\mu H.r - \lambda_{H,r}} + \frac{\ln\left(\frac{N - \frac{N}{m_H}}{N-1}.d_H + 1\right) + 1}{\mu_{H.l} - \lambda_{H,l}}$

Where λ – the average number of flow requests per second from one host to another
μ_c – the average receipt rate of the flow request
λ_c – the average processing rate of flow requests by controller
N – the number of network nodes
m_D – the number of controllers in a decentralized structure

d_D – the average distance to the controller in a decentralized structure

$L_{D,l}$ – the queue length for each controller in a decentralized structure

$\lambda_{D,l}$ – the receipt rate of the flow initiation request for each controller in a decentralized structure

$\mu_{D,l}$ – the average service rate of controller in a decentralized structure

m_H – the number of controllers in a hierarchical structure

d_H – the average distance to the controller in a hierarchical structure

$\lambda_{H,r}$ – the receipt rate of the flow initiation request for each controller in a hierarchical structure

$\mu_{H,r}$ – the average service rate of controller in a hierarchical structure

Based on the above presented formulas, we calculated scalability for SDN management level, shown in Table 3 [10].

Table 3. Scalability for SDN management level

SDN network structure	**Scalability for SDN management level**
Centralized structure	$\psi_c(N_1,N_2) \approx \dfrac{K - N_2^4.\lambda}{K - N_1^4.\lambda}$
Global decentralized structure	$\psi_{D,g}(N_1,N_2) \approx \dfrac{K.m_D - N_2^4.\lambda}{K.m_D - N_1^4.\lambda}$
Local decentralized structure	$\psi_{D,l}(N_1,N_2) \approx \dfrac{K.m_D^4 - N_2^4.(d_D.m_D - d_D + m_D)\lambda}{K.m_D^4 - N_1^4.(d_D.m_D - d_D + m_D)\lambda}$
Hierarchical structure	$\psi_H(N_1,N_2) \approx \dfrac{K.m_H^4 - N_2^4.(d_H.m_H - d_H + m_H)\lambda}{K.m_H^4 - N_1^4.(d_H.m_H - d_H + m_H)\lambda}$

5. Simulation of Centralized, Local Decentralized, and Global Decentralized Management Level Structures

Different approaches of building SDN management level architecture were studied. In the MiniEdit software environment, a simulation model of SDN network was developed for different topologies (Fig. 13). To confirm the efficiency of the network, connections between network nodes were tested. After running the network, its performance was tested by using the *pingall* function.

a – the model of centralized management architecture; b – the management level model of global decentralized architecture; c – the management level model of local decentralized architecture

The network data rate was also studied with the *ping* command. The first packet has the longest transmit because the initial switch has no corresponding record in the flows table. When the first packet arrives, the switch sends it to the controller. The controller decides and instructs all switches to add information about this way to the flows table. After that, the switch will not ask the controller how to process these packets, and will transfer according to its flows table. When a switch does not have information about an arriving packet, the switch will again send a request to the controller regarding the packet flow.

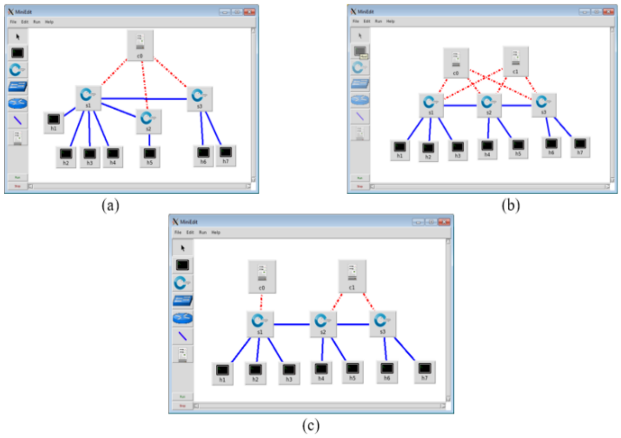

Figure 13. A simulation model for different SDN network topologies:

We verify the change in transfer rate with the increasing number of hosts. Firstly, leave the network as in Fig. 13, but increase the number of hosts to 34. When the number of nodes increases, the network scalability becomes worse, but with a small number of hosts, the effect is not so noticeable because the difference in scalability is insignificant. With a large number of hosts, the network may not work at all.

Next, we conduct research on the bandwidth of centralized management level structure. For this purpose, we created a simple HTTP server based on host h1 (Fig. 14).

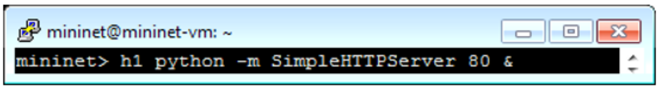

Figure 14. Creation of the server

For this test, host h2 attempts to access and download data from host h1 by using command *h2 wget – O – h1*. Server answers the *wget* command after it is sent from host h2 by sending an *ACK* response. Having received the *ACK* response, host h2 has access to the necessary data on the server on host h1. The data transfer rate in this case is 66.9 Mbit/s. The same test was conducted for other types of structures, and the results are shown in Table 4.

Table 4. Average data rate for a request in different SDN network structures

SDN network structure	Average data rate for a request
Centralized structure	66.9 Mbit/s
Decentralized structure	137 Mbit/s
Hierarchical structure	142 Mbit/s

The data rate in a hierarchical structure is 142 Mbit/s, which is higher than in a centralized and global decentralized architecture. This shows that the local decentralized approach to building network architecture is better in comparison with centralized and global decentralized one with regard to data rate.

6. Conclusions

We can safely state that 5G technology will become the new standard in the mobile communication market. New networks will be focused on substantial improvement of characteristics for service quality. The demands that users make on mobile broadband networks primarily relate to performance. The development of modern networks is trending toward immediate data access and service provision without delay and without interruptions caused by unreliable service. 5G cellular networks will focus on the quality of customer service and should be built focusing on the needs of users, and the basis for their construction will comprise SDN networks. Therefore, the advantages and disadvantages of two SDN implementation methods were analyzed. We determined that Overlay networks can be built on top of any modern IP network without replacing equipment, and in addition, they can be built on optical networks. However, compared with a hardware approach, such networks have a greater delay.

The simulation of Overlay network operation was conducted using an Open vSwitch via Mininet and MiniEdit. Mathematical calculations were conducted in the software Mathcad, which was used to create dependency graphs of average delay on the number of packets in the flow and the number of switches in each network. Analysis of the results shows that the use of SDN networks is more efficient by using IP networks for large volumes of traffic and with a large amount of network equipment. Models of management level structures were built for centralized, global decentralized, and local decentralized architecture, and these approaches were compared to the build management level architecture of SDN. The local decentralized approach has better scalability compared to centralized or global decentralized approaches, which is evident from the experimental results showing that the local decentralized network has the best performance in data rate and request rate processing. When the number of hosts increases, the local decentralized network has better performance compared to other structures with the same number of hosts. Using the architecture with distributed controllers is proposed because it has better reliability. Although such a network is less scalable, it has a great advantage, because in the case of failure of one or more controllers, the network remains operational and will transmit data for as long as the functionality of some controllers is maintained.

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