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IMPROVED PERFORMANCE OF 5G BASED SOFTWARE DEFINED NETWORKS

Zinah O. Nori [1], **Abdulkareem A. Kadhim** [2]
[1] Department of Network Engineering, College of Information Engineering, AL-Nahrain University, Iraq
[2] College of Engineering, Al-Mustaqbal University, Babylon, Iraq
zeena.usama3@gmail.com , ak.kadhim@uomus.edu.iq
Corresponding Author: Abdulkareem A. Kadhim
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***Abstract*- With the growth of processed data for wireless networks and the establishment of new applications and services, mobile operators keep searching for solutions to deal with the issues raised by nextgeneration networks (NGN). The fifth generation (5G) mobile networks, for example, should enhance their performance without consuming a lot of energy. For these reasons, software-defined networks (SDN) appear to be the promising technology that will make achieving the architectural agility required for the upcoming 5 G mobile networks easier. SDN is a clever solution for providing innovation and enforcing the primary drivers in $5G$ mobile networks, such as flexibility, dependability, service-oriented management, and cost reduction through the control and management of the 5G core network. In this paper, the integration of SDN and multiple controllers with the 5G core network is investigated to determine how these two technologies can affect mobile IP network performance. An energy model suitable for the proposed network architecture has been developed. A widely used Diamond network is being considered for the core network. Open-Flow controllers were used to improve the routing performance by considering load balancing of IP traffic. According to such a model, reduced energy consumption is experienced with SDN. The addition of an SDN controller results in a 11% reduction in consumed energy. The results also show that the use of SDN and multi-controller with NGN can improve the performance further. Using SDN reduced the average delay of the network by 14%. A great reduction in packet error rate (PER) is also achieved when SDN is used.**

keywords: **5G, NGN, SDN, energy consumption, throughput, packet error rate, and QoS**

I. INTRODUCTION

With the inspiration of a number of supporting technologies, the development of software-defined networks (SDN) started in the early years when the network control used in telephone networks was in such technology. The data and control are dispersed. This provides security and performance efficiency. Active Networks technology introduced network programmability via an application interface. Even though these technologies were discovered earlier, they were not implemented due to a lack of sufficient hardware support and the already expensive established infrastructure [1]. With the launch of Open-Flow in 2008, the main contribution to SDN began. [2]. On the other hand, modern wireless mobile networks have seen exponential growth in a variety of applications and services. One of the main goals of 5 G is to provide various types of devices, applications, and objects that are connected to each other. With this growth of connected devices, data traffic, services, and related issues need to be addressed by the next generation networks (NGN) [3].

Many research efforts have focused on the use of SDN with NGNs such as 5G cellular wireless networks The main goal of such efforts is to simplify network control and management. SDN also helps in supporting higher traffic and reducing energy consumption [4]. The following provides an overview of related research: In [5] and [6], the authors proposed a plastic architecture that is based on 5G networks with SDN. This architecture is based on the separation of the control plane (CP) and the data plane (DP). And with the CP, there are three levels of control, namely: device, edge, and orchestration

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control. These layers have different functions in the network, like providing connection, routing, mobility, and security. This architecture can reduce end-to-end latency and improve reliability.

A 5G system architecture that is used to support different services and applications like connected cars and ehealthcare is proposed in [7]. This architecture is based on SDN and Network Function Virtualization (NVF) in order to make the architecture more flexible. Additionally, new features have been added, including mobility management, a quality of service (QoS) framework, and session management. In [8], the authors proposed a method to apply SDN to the 5G architecture. By the use of this method, the function of control is moved from the gNodeB (gNB) to the SDN controller, where gNB performs data plane functions only. It is shown that this method results in reduced signaling costs and improved network performance.

A robust 5G security architecture that is based on SDN to detect illegal requests from malicious attackers is proposed by [9]. An extra cryptographic authentication named "synchronize secret" was added to the network. The fundamental concept is to use preload secrets to distinguish attacks from normal network connections. According to the findings, the work is significantly more effective than state-of-the-art in in dealing with the security issue from SDN, with a small disconnect rate of about 0.01 percent.

References [10] and [11] mention the network slicing (NS) architecture in 5G can guarantee QoS for different applications. This architecture works by dividing the network into different parts. Different network resources will be specified for each part, and according to these metrics, each packet will be routed to the most suitable network part to guarantee the desired QoS.

In [12], the authors proposed a device-to-device (D2D) handover schema that is based on SDN. This method is in charge of managing D2D communication as well as mobility issues. It is shown that this schema can help in decreasing the number of signaling messages that are needed for the handover process between D2D and, in addition, the proposed schema decreases latency and average delay time. Using a Logically Centralized-Physically Distributed (LC-DP) controller architecture with the 5G networks, the authors in [13] showed that using such an architecture can improve the performance of the 5 G networks by providing low latency and higher throughput in comparison to other controller architectures.

In [14], the authors proposed a Cloud Radio Access Network (C-RAN) architecture for 5G networks. This architecture is based on the separation of the baseband units (BBU) from the gNB and combining them into one place. The proposed architecture is based on the idea of SDN and shows a major reduction in the signaling load as compared to other traditional networks. It also improved the flexibility of the network programming and the simplicity of management. A unique machine learning-based solution for QoS provisioning in multimedia 5G SDN networks called "Learn SDN" was proposed in [15]. This method uses machine learning to determine the most suitable routing algorithm to use on traffic based on network conditions in order to meet the QoS requirements of multimedia traffic. The results show that the QoS of Learn SDN is better than other technologies.

The above-mentioned research efforts were focused on the use of SDN with 5G networks to solve the problem of performance issues such as average delay and time jitter. In this paper, the use of SDN is examined with single and multiple controllers when used with 5G as an example of NGN. The issues of energy consumption, packet error rate

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(PER), and throughput are to be investigated in addition to the average delay and time jitter.
The rest of the paper is organized as follows: the proposed architecture with related parameters is described in Section II. Section III introduced the performance measures used in the simulation tests and their results covering average delay, time jitter, throughput, PER, and energy consumption of the 5G network with and without SDN. Finally, Section IV concludes the paper.

II. The Proposed Architecture

Three different network architectures are considered in this work. The network scenario consists of two mobile base stations with 10 users (UEs) residing in each cell. Both cells are connected to the core network via a gateway (PGW).

The first network architecture is just 5G mobile networks and the core network without SDN. In the second architecture, an SDN controller and Open-Flow switches are added, while the third is similar to the second but with multiple controllers. The Open-Flow controller is used to improve routing through load balancing of IP traffic to improve QoS. The network topology follows a commonly deployed diamond network in the 5G core network. In the diamond architecture, the network has multiple routes between different network nodes, which ensures the network's robustness and reliability. The Diamond network has a low probability of congestion than other networks due to the even distribution of traffic [16]. The diamond network in the present work consists of five network switches arranged in a shape that looks like a diamond.

The 5 G environment is created in the OMNeT++ simulator together with the Open-Flow and simuLTE add-ons. Fig. 1 shows the adopted 5G network without SDN. UES are placed at a distance ranging from 100 to 300 m from the gNB randomly. PGW is used to connect the access network to the core network. The core network consists of five switches and a server. Each UE sends IP packets with the destination address of the server. The PGW then forwards this packet to the core network. The switches continue the forwarding of the packet until it reaches its destination (the server). After generating and routing each packet, the performance parameters are recorded in the OMNeT++.

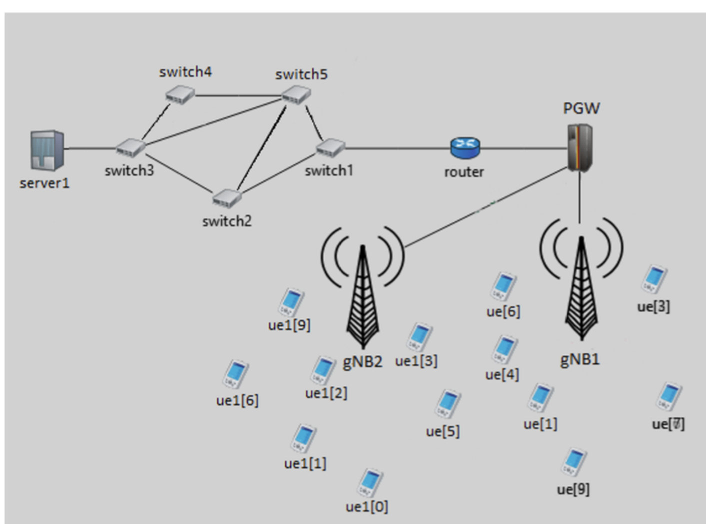

Figure 1: 5G network without SDN

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In the second scenario, an SDN controller is added as shown in Fig. 2. The configuration of the access network is the same as that in Fig. 1, with the addition of an Ethernet interface in PGW to pass the rules of the controller from the core network to the gNB cells. The core network is modified by replacing the switches with Open-Flow based switches. Both the controller and the switches use the Open-Flow protocol to communicate. Considering this protocol, the link layer discovery protocol (LLDP) is used to construct the entire network topology. The switches are configured to work in proactive mode where the flow can be inserted proactively by the controller into the switches before the packet arrives. As before, each UE sends a packet with the destination address of server1. When the packet arrives at the core network, the switch checks the packet's source and destination addressees and one of the following two actions will be performed. Assuming the packet is on the local switch, the packet will be sent to the destination directly. If it is not on the local switch, the switch sends the packet to the Open-Flow controller for additional routing until it reaches its intended destination. When an Open-Flow controller receives a packet, it will be transferred to its appropriate destination address.

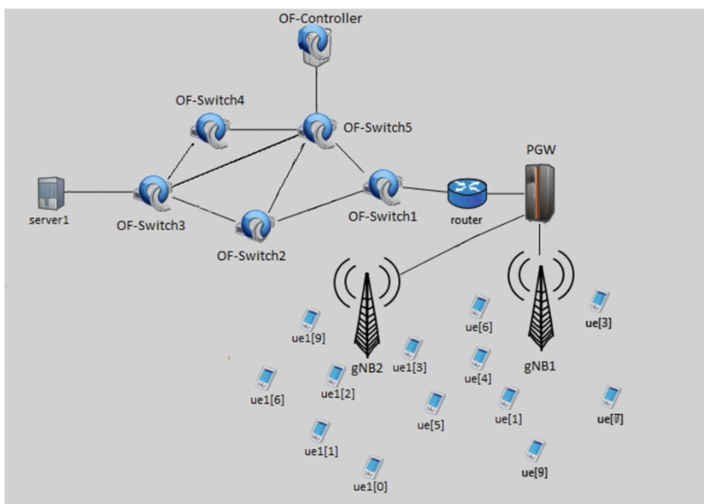

Figure 2: 5G network with SDN controller and switches

In the third scenario, two controllers are added with a synchronizer as shown in Fig. 3. The access network has the same configuration as before. In the core network, two controllers work together to achieve better performance and scalability. In this centralized architecture, the controllers are placed in a centralized location and are connected through a synchronizer called the Hyper-Flow protocol [17]. The Hyper-Flow protocol performs load-balancing for the traffic between controller#1 and controller#2. An instance of Hyper-Flow is enabled on each controller. Each switch must be connected to the controller that is in close proximity to the given controller.

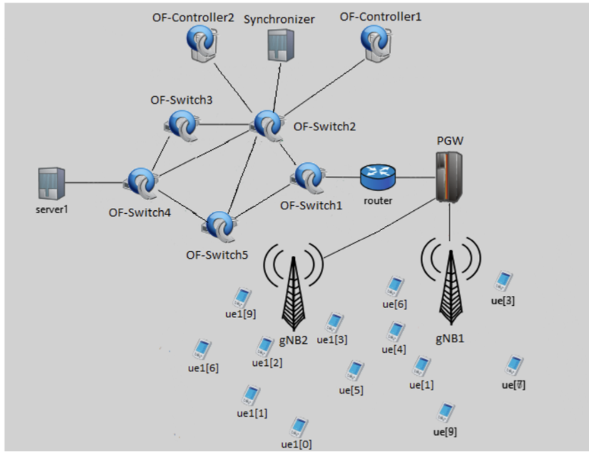

Figure 3: 5G network with multi-controller controllers and Hyper-Flow

In the adopted architecture, switch#1 and switch#2 are connected to controller#1, while switch#3, switch#4, and switch#5 are connected to controller#2. When using Hyper-Flow, the first packet in the queue is sent to controller#1 and the following packet is sent to controller#2. The UES connection to their cells and to the core network server is similar to that of the SDN network in scenario#2. The only difference here is the addition of two load balance controllers to distribute the workload among the two controllers. Each switch takes the rules from its designated controller, which reduces the congestion experienced with a single controller.A set of simulation parameters are considered to evaluate the performance of the considered network architecture. Table I provides a list of the parameters and test modules used in the simulation tests.

TABLE I
THE CONSIDERED SIMULATION PARAMETERS

Item Description	Value/Type
Application	UDP Basic App.
Path loss	1
Carrier Frequency	2.4 GHz
Total number of packets	100,000
No. of bytes per packet	100
No. of UEs per cell	10
No. of switches/routers	6
No. of controllers in SDN	1 or 2
Simulation time	75 s

III. Results and Discussion

A. *Performance Measures*

Different metrics are considered to evaluate the performance of the given network topology when the three assumed scenarios are simulated according to the above description. The performance metrics or measures used are average delay, time jitter, throughput, PER, and total energy consumption. For NGN to gain better QoS, Lower PER, average delay, time

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jitter, and energy consumption with higher throughput are preferred.The network average delay time is referred to as the average amount of time taken for all packets to reach their intended destination as given by (1) [18]:

$$\tau = \frac{\sum_{i}^{N} (T_{r,i} - T_{s,i})}{N_t} \tag{1}$$

Where τ is the average time delay, N_t is the total number of packets, $T_{r,i}$ and $T_{s,i}$ are the times of receiving the i^{th} packet and sending the i^{th} packet, respectively.

The average time jitter is the average time difference between the time delay of two successive packets [19], and is given by (2):

$$J = \frac{\sum_{i}^{N_t} (\tau_i - \tau_{i-1})}{N_t} \tag{2}$$

Where J is the average time jitter, and τ_i and τ_{i-1} are the delay of the i^{th} and $(i-1)^{th}$ packets. The expression for the packet error rate (PER) [20], is shown in (3);

$$PER = \frac{N_t - N_c}{N_t} \tag{3}$$

Where N_c is the number of correctly received packets at the intended destination.

The throughput of the network is given by the ratio of the correctly received data units (packets or bits) to the total transmission time [18]. Here we consider a packet per second as the unit for the throughput (Thr.) as given in (4);

$$Thr. = N_c/T_t \tag{4}$$

where T_t is the total transmission time.

An energy model should be developed to estimate the energy consumed by the network for the transmission and reception of all packets. A verified energy consumption model is followed, which was considered previously by [21]. Three modes are presented: transmission, reception, and idle modes. For simplicity, the idle mode is ignored here due to its minor effect on the calculated energy. Based on the simulation time set and the total number of the transmitted packets and the number of bytes per packet Table I, the energy consumption (E) is determined. Let T be the device operation time and V be the voltage level (5 Volts), then the estimated energy is given by;

$$E = T.I.V \tag{5}$$

Where I is the required current to process one packet. The current value for the transmission mode is 280 mA , while for the reception it is 230 mA [21].

B. Simulation Results and Discussion

Performance evaluation is performed by the simulation of the adopted network topology with and without SDN. In either case, the used application is "UDP Basic App," which sends UDP packets to the given IP address at the given interval.

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Following the description of the system in Section-II and its parameters given in Table I, the results are determined for the network considering three cases: the traditional 5G network; the SDN based 5G network using a single controller with Open-Flow protocol; and the SDN based 5G network with two controllers using Hyper-Flow protocol. Fig. 4 shows the average delay time performance. The results show that the network without SDN has an average delay of 35 ms , while the SDN case with a single controller is 32 ms , and the network with two controllers and Hyper-Flow protocol is about 30 ms . Considering the time jitter performance shown in Fig. 5, a 11 ms is experienced in traditional 5G network, while for SDN based network with Open-Flow and Hyper-Flow is about 9 and 8 ms , respectively. Since the controllers in the SDN-based network have an entire view of the network, they can easily choose the least congested route in the network to route the given packets. This will result in a reduction of 14% in the average delay time compared to the traditional network without SDN. The corresponding reduction in time jitter is about 27%.

The PER performance is shown in Fig. 6. The results show that the traditional 5G network achieved PER of 2.7×10^{-4}, while in the case of SDN networks the PER is about 1.6×10^{-4} and 1.5×10^{-4} for the Open-Flow (single controller) and Hyper-Flow (two controllers) networks, respectively. It is worth mentioning here that the present work deals with studying the effect of using SDN on 5G network performance. The effect of the variations in the wireless physical channel, noise level, and signal power is subject to another investigation performed by the authors, whose results have not been published yet. Here, the path loss represents the channel quality considered in the simulation, which is selected to be common for the three considered scenarios, bearing in mind that the work is focused on the advantage of SDN for a given transmission environment.

Fig. 7 shows that improved throughput performance is experienced with SDN-based networks. The SDN network with Hyper-Flow is better than that of an SDN network with Open-Flow. The main reason for the relatively poor throughput performance of traditional networks without SDN is the effect of congestion. The latter has limited effect in the case of SDN-based networks.

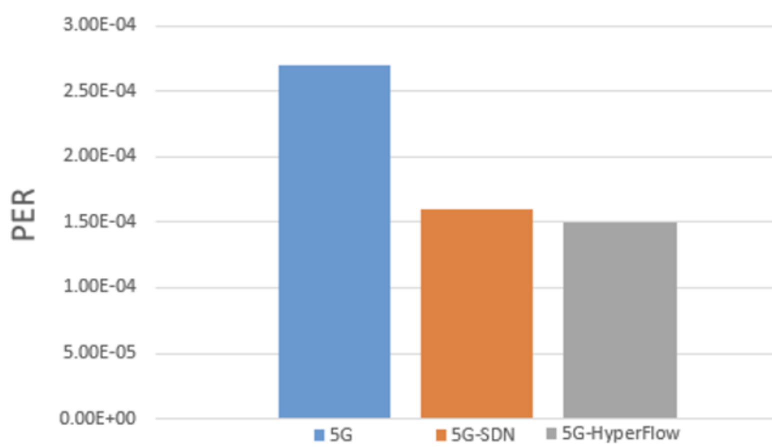

Figure 4: Average delay performance

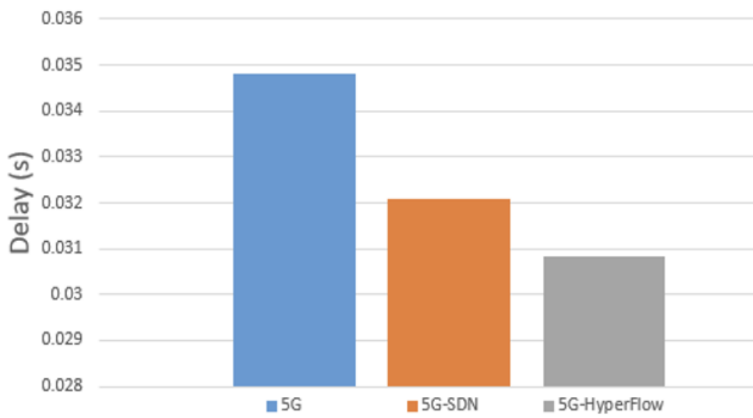

Figure 5: Time jitter performance

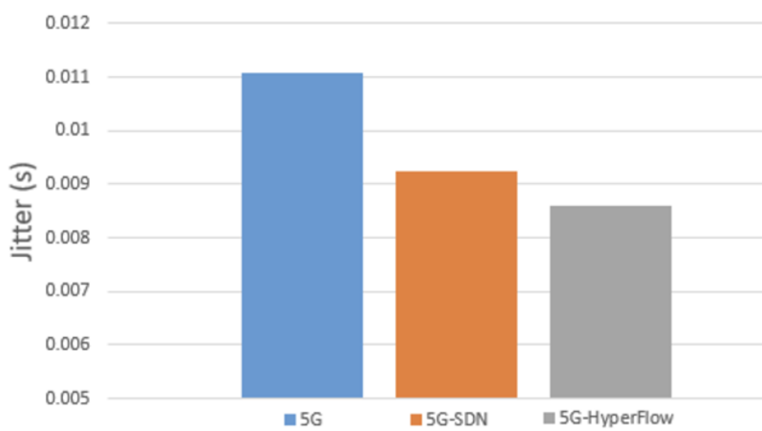

Figure 6: Packet error rate performance

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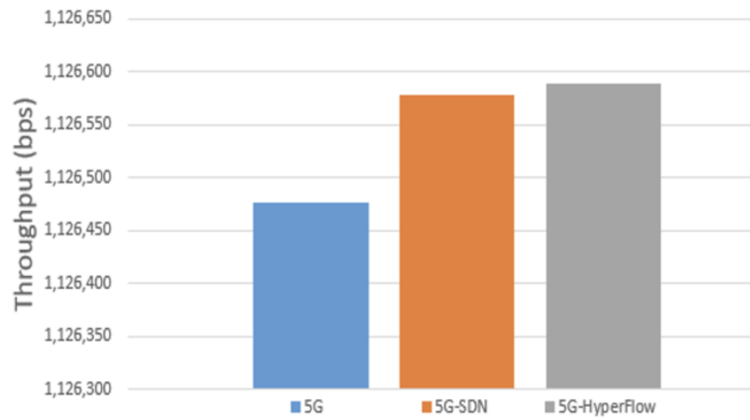

Figure 7: Average throughput performance

Fig. 8 shows the energy consumption of the three cases: the traditional 5G network; the SDN based 5G network using a single controller with Open-Flow protocol; and the SDN based 5G network with two controllers using Hyper-Flow protocol. The energy consumption is calculated according to (8), where T is the time required to send or receive each packet. The results in Fig. 8 show that the traditional network without SDN consumes about $6.2\ \mathrm{mJ}/$ packet, while for the network with SDN using Open-Flow it is about $5.51\ \mathrm{mJ}/$ packet and for SDN with Hyper-Flow it is about $5.55\ \mathrm{mJ}/$ packet, respectively. Thus, the network with SDN consumes about 11% less energy compared to a 5G network without SDN. The main reason for such an improvement is the use of controllers in SDN-based networks. The controllers have full information about the entire network, and they make use of such knowledge in forwarding each packet with the least number of hops, resulting in reduced energy consumption due to the reduced of operating time of the network devices. The consumed energy for an SDN-based network with the Open-Flow protocol ($5.51\ \mathrm{mJ}/$ packet) is slightly better than that of the network with Hyper-Flow ($5.55\ \mathrm{mJ}/$ packet). This is due to the additional controller actions that are added to the network load. As a result, one can say that the use of two controllers (Hyper-Flow protocol) can improve the performance by solving the problem of a single point of failure at the expense of slight energy consumption compared to a single controller (Open-Flow protocol) SDN-based network

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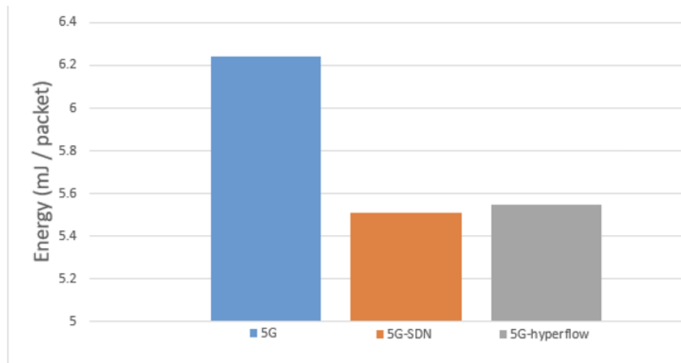

Figure 8: Energy consumption performance

IV. Conclusion

Software defined network (SDN) based 5G network architecture is considered to facilitate the network operation and management. In addition to the traditional 5G network, two new architectures were proposed: the first with a single SDN controller using the Open-Flow protocol and the second with two controllers using the Hyper-Flow protocol. The mentioned networks have been simulated using the OMNeT++ simulator with simuLTE and the Open-Flow add-on. It is shown that the use of SDN-based network with a single or two controllers can improve the network performance. Different performance measures were used to assess the operation of all networks. These measures covered the average time delay, the time jitter, the packet error rate, the throughput, and the energy consumption. The results showed that about a 14% improvement in the average time delay is achieved by using SDN with a multicontroller architecture compared to the traditional 5G network. The corresponding improvement in time jitter is about 27%. The PER and throughput are also improved when SDN is considered in the networks. The improvement is achieved in both cases of single or two controllers, with slightly better performance experienced in the case of two controllers. The network with SDN consumes about 11% less energy compared to a 5G network without SDN. The cost of the presented improved performance of SDN-based networks is the required upgrading of the network devices needed by SDN implementation. It is worthwhile to investigate the use of multi-controller based SDN with next generation networks.

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CONFLICTS OF INTEREST

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